DEVELOPMENT OF CREEP TESTING MACHINES FOR SPHEROIDAL GRAPHITE CAST IRON

H. S. KENNEDY

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MONTEREY, CALIFORNIA

Development
of
Creep Testing Machines
for
Spheroidal Graphite Cast Iron.

A thesis submitted in partial
fulfilment of the requirements
for a Diploma of the College of
Aeronautics.

by

Lt. H. S. Kennedy, U. S. N.

Cranfield, Bedfordshire
England.
5th June 1954.

Thesis
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Summary

Recent developments in the gas turbine field have led to the need for creep data on spheroidal graphite cast iron.

The development of two creep testing machines suitable for this material was undertaken. Due to the size of the test piece specified, the elongation of the material and the speed of tests several modifications had to be made to these machines before a satisfactory procedure could be established.

The creep data, obtained during the development period, and presented herein, give some indication of the order of magnitude that may be expected from a thorough programme of creep testing on this material.

Introduction

Creep is the continued extension of a material after the load has been applied. Glass and lead are well known examples of materials that creep at room temperature. However with most metals used in engineering industries an additional factor of temperature must be considered. That is, the extension takes place much more rapidly at elevated temperatures.

This extension of material will lead to failure in one of two ways. It can actually fracture or it can deform sufficiently to become unserviceable.

The need of testing to determine creep properties was greatly increased by the introduction of the gas turbine type of engine into the aeronautical field. Recent developments in this line of engines have led to the consideration of spheroidal graphite cast iron as material for use in their construction.

Spheroidal graphite cast iron is a new material that in recent years has been finding increasing use in many applications in heavy engineering, chemical industry and surface transport. However, very little was known about its properties at elevated temperature.

Therefore, in agreement with the Mond Nickel Company Limited, it was decided to construct a pair of creep testing machines capable of obtaining some of the data that was desired.

Part 1

Development of the Machines.

DEVELOPMENT OF CREEP TESTING MACHINES

1.1 GENERAL DESCRIPTION

The two machines that were constructed are basically a design developed by the National Gas Turbine Establishment. The policy during the construction period was to adhere to the specifications and drawings of the machines as supplied by N.G.T.E. In several instances modification had to be made to adapt the machines to spheroidal graphite cast iron (S.G.C.I.)

In general, there are two types of constant load creep machines in common use at the present. There are the dead load type and the lever type. The lever type has the advantage of requiring smaller weights, but does need more floor space. The machines developed for S.G.C.I. are of the lever type.

The actual set-up consists of the following components:

1. Machine proper for applying the load.
2. Furnace for maintaining temperature.
3. Controller for controlling the temperature.
4. Potentiometer for measuring the temperature.
5. Extensometer for measuring the elongation.
6. Cameras and timers for recording the extensometer and hour meter readings.

A general view of the machines and controls is shown in figures 1 to 5.

1.2 The Machine.

1.21 The Frame.

A general arrangement of the frame for supporting the loading system is shown in figure 6.

The main members of the frame are four inch by two inch channels, while the lever support system at the rear of the machine is made of one and one half inch angles.

The cross head at the top of the machine is in two parts. The lower part carries the load from the upper straining rod to the side members. The upper straining rod is keyed to the cross head to prevent the introduction of any torque in the test specimen while taking up the strain.

The upper part of the cross head supports the furnace hanger plate.

There is a chain and sprocket adjustment for the height of the furnace. The chain drive insures that both furnace support rods are adjusted to the same position simultaneously.

The fulcrum for the loading system is supported by the cross member on the front of the machine.

The lever support yoke is carried by the cross member at the rear of the machine. This yoke was originally

intended to support the weights prior to loading and to catch the beam when the test specimen fails. Modifications to this yoke will be discussed in section 1.10.

1.22 Loading System.

The loading system consists of a weight pan, lever, fulcrums, and the upper and lower straining rods.

The weight pan is supported on the beam by a 3/8" diameter hardened steel ball.

The lever which has a ten to one ratio carries two knife edges at the forward end for the fulcrums. Modification to the fulcrums will be discussed in section 1.10.

The straining rods are identical, except for the length of the rods. They consist of a collar, nut, and the rod itself. The collar with a spherical seat attaches to the end of the test piece. The nut fits over the collar, mating with the spherical seat, and is threaded to fit the straining rod. The other end of the rod is forked. The upper straining rod fits into a universal joint on the strain take-up mechanism and the lower rod fits on to the fulcrum carrier. Here again modifications were found necessary and will be detailed in section 1.10.

1.23 Weights.

The weights are made from mild steel plate, three quarters inch thick. Due to misinformation about the

diameter of the test piece, the weights as manufactured give a stress, that is, not an even ton or fraction thereof. They give stresses of 0.92, 0.47, and 0.25 tons per sq.in. respectively.

1.3 Furnace.

A general arrangement of the furnace is shown in figure 7.

The furnace consists of a silica tube, around which the element is wound. To give the element mechanical support, it is coated with alumina cement. The tube is then surrounded by a preformed insulation that is a mixture of asbestos and Kieselguhr. This is then surrounded by a stainless steel liner. This liner is covered by a preformed asbestos insulation which is finally covered by a stainless steel outer case. The ends are Sindanyo plates.

Between the silica tube and the inner insulation, there is mounted a platinum resistance thermometer that is part of the temperature control system.

The leads to the two coils, top and bottom, are brought out at the top and the bottom, respectively.

The furnace is held together mechanically by four tie bolts that connect the upper and lower end plates. These tie bolts are not bolted down directly on the Sindanyo end plates, but have a spring between the upper end plate and

the nut and washer. This prevents any undue stress due to differential expansion of the metal parts, being put on the Sindanyo. The upper ends of these tie bolts carry the support beams which are attached to the furnace hanger plate by means of short links.

1.4 Extensometer.

The extensometer consists of two rods attached to upper end of the test specimen and two tubes attached to the lower end of the specimen. The rods pass inside of the tubes and extend beyond the tube ends approximately one inch.

A small chuck clamps on to the lower end of the tube and carries a dial gauge graduated in 0.0001 inches. This gauge then measures the displacement of the rod end with respect to the tube. Since the rod and tube are subjected to essentially the same thermal conditions, this is an accurate indication of the elongation of the test specimen.

The modification to the extensometer will be explained in section 1.10.

1.5 Test Piece.

The test piece, as shown in figure 10, has a nominal diameter of 0.357 inches. This gives a cross sectional area of 0.100 square inches. The tolerance of 0.001

results in an error of approximately 0.5% in area and hence in stress. The parallel portion of the test piece is 4 inches. The threaded ends are 5/8 inch BSF.

As shown in figure 10, the surface of the test piece was ground polished to eliminate all stress raising machining marks.

1.6 Temperature Measurement.

In accordance with reference (1), the temperature of the test specimen was measured at three points, top, middle and bottom. The temperature was measured by chromel-alumel thermocouples. Each thermocouple was calibrated prior to use and was used only twice, the ends being reversed for the second test.

The developed potential of the thermocouples was measured by an Ether Long Scale Potentiometer. This instrument has a sensitivity of 0.02 millivolts at the working temperature (450°C). This corresponds to a temperature of 0.5°C.

To provide a means of checking the temperature regulation during periods of absence, the temperatures were recorded on an Electroflo temperature recorder, connected to one of the thermocouples. While this recording was not accurate enough for the measurement of the temperature, it did show if any drastic changes in the temperature level

did occur. A sample of the recording chart is shown in figure 11.

1.7 Temperature Control.

The temperature of the test specimen is controlled by the variation in the resistance of a platinum wire made in the form of a mat. The platinum wire is protected by fire clay insulators. Modifications to the resistance thermometer are detailed in section 1.10.

The control of the furnace current utilized a Sunvic RT 1 controller. This controller is essentially a Wrosser bridge for measuring the resistance of the platinum thermometer and a relay for opening the furnace power circuit.

Since turning the furnace completely off and on, to maintain temperature would result in a great deal of hunting, with consequent difficulties of control, the controller was by-passed by a variable resistance as shown in figure 8. Thus, we have a high and a low current rather than and on-off cycle. The currents maintained in these tests were 6.9 and 4.5 amperes respectively.

Equality of temperature on the top and bottom of the test specimen was obtained by varying the current to the two coils of the furnace by means of a central balancing rheostat.

This system has proved capable of controlling the temperature within the limits specified in reference (1).

1.8 Automatic Recording.

The individual tests in this programme range from one and a half hours to three hundred. In the tests that have a duration of fifteen to one hundred hours, some method for automatically recording the gauge readings had to be employed. Ripon in reference 3 describes such a system.

The components of this system are a camera, a timer, and a rectifier. The camera is an Air Ministry gun camera. It has a fixed shutter speed and a two position lens diaphragm. It takes pictures at sixteen frames a second. The timer was designed and built in the Electrical Section. It will give time intervals of one to sixty seconds. The rectifier supplies low voltage D.C. for the operation of the camera and the timer.

By the use of an external clock, the interval between recordings can be increased. At present there are two such clocks available. One has intervals of fifteen minutes and the other, four hours.

1.9 Verification of the machine.

When new testing machines are built, it is essential to verify that these machines will do that which they are designed to do. The main points to be checked were the loads produced by the weights, the axiality of the loads

and the elastic gauge length of the extensometer.

In order to check the loads introduced by the weights, the straining rods and the test piece were replaced by a Salter spring balance. This balance had a range of 0 to 600 pounds, with two pound divisions. Reading it to the nearest pound was easily accomplished. The weights were then individually checked. The beam and the weight pan produce a stress of approximately 0.45 tons per square inch in the designed test piece. The weights were found to give approximately 0.92, 0.47 and 0.25 tons per square inch respectively. A complete list of the values obtained for each individual weight is shown in table I.

The axiality of the loading was next checked by comparing the movement of the dial gauges on each leg of the extensometer. This was done in four positions, with the test piece turned ninety degrees between each reading. At first the loading on the machines was not nearly as axial as was desired. After certain modifications the axiality of the loading was well within the requirements of B.S. 1687.

Since the extensometer is mounted on the threaded portion of the test piece (figure 9), it measures more than the elongation of the parallel length of four inches. To check this the extensometer readings were compared with readings taken on a Hounsfield extensometer attached to the parallel portion. The elastic gauge length of extensometer and test piece was found to be 4.15 inches.

1.10 Modifications.

1.101 General Considerations.

In the course of preliminary testing certain modifications to the machines, as designed by N.G.T.E. were found to be necessary to adapt them for the testing of S.G.C.I. at stresses that would produce failure in the short periods that were desired. These modifications were occasioned by a combination of two factors, the speed of the tests and the exceptional elongation of the material before it fails.

The speed of the test compresses all of the phenomena that occur in a creep test into a much shorter time. It is practically impossible to prevent the machine unloading itself, especially in those tests that last twenty to fifty hours. In the shorter tests it is possible to be in attendance throughout and make the necessary adjustments. In the longer tests the need for adjustment is not so frequent and can be met quite easily.

The elongation of S.G.C.I., under the test conditions, is of the order of twenty-five percent at fracture. In a four inch gauge length this amounts to an extension of one inch. When this is multiplied by the ten to one beam ratio, it results in a travel by the weights of ten inches. This is obviously not practical.

To overcome the above deficiencies the following modifications were made.

1.102 Lever Support Yoke.

As originally designed the lever support yoke provides a means of supporting the lever prior to loading and of catching the lever when the specimen fractured. Unfortunately since the travel of the beam allowed by the opening in the yoke was small, about one inch, the yoke would catch the beam during the test and remove the load.

To overcome this difficulty, first of all, the thread on the stem of the yoke was lengthened. While this did not prove to be completely satisfactory, it did improve the situation.

The pin at the bottom of the yoke was originally fixed. This pin was then made removable, which makes the machine satisfactory for these tests. However, there is some objection to this since, when the test piece fails, the weights drop to the base of the machine. This causes a considerable impact loading on the machine and surrounding floor.

It is felt that a more satisfactory method would be to have an automatic strain take-up system. Such a further modification is recommended in Section 1.112.

1.103 Loading System.

The original design of the loading system called for close tolerances, both between mating parts of the universal joints and on the threaded portions of the straining rods.

These close tolerances produced a very definite stiffness in the system that made it very difficult, if not impossible to load the test piece axially. The tolerances were increased to give an easy fit on all parts.

As an additional, but equally important, change to secure axiality the radius of the spherical seats on the straining rod nuts and collars, was reduced from 1.1/2" to 1.1/8". This increases the lateral force tending to centre the test piece.

It is felt that these modifications, in conjunction with proper packing of the asbestos in the furnace tube (section 2.1), ensure the axiality of loading, within the requirements of B.S.1687.

1.104 Furnace.

The N.G.T.E. furnace winding was originally designed for the temperature range of 700°C. to 900°C. In following the policy of adhering to the original design, one furnace was constructed to this design. However, it proved to be very unsatisfactory at 450°C. It was impossible to maintain the temperature within the requested limits, although several systems of connecting it to the mains were tried. Also, with the use of Variacs it was very difficult to secure adequate current to keep the furnace at 450°C. Therefore, another winding was designed.

This redesigned winding was made of Brightray "C" 18 swg

instead of 19 swg. This decreased the resistance by about 40%, thus allowing more current to be passed.

The design of the new winding was based on the assumption that a major portion of the heat that raised the temperature of the test piece flowed from the straining rods. These rods are, of necessity, much longer than the specimen and they require most of the energy used by the furnace. Consequently, a two coil furnace was constructed. The winding spacings are shown in figure 13. It will be noted that the bottom winding is longer and has more turns than the top. This is to offset any convection currents within the central furnace tube.

This winding has shown itself capable of being controlled and of attaining the proper temperature.

1.105 Extensometer.

The extensometer is a simple mechanically rugged type that is well suited to the degree of accuracy desired in this programme. It had two major faults however. The range of the instrument was seriously limited and the dial gauges had a tendency to stick.

The original gauges had a travel of 1/4". These were replaced by gauges having a 1/2" travel, which is the largest commercially available. Even with this length of travel, the gauges had to be moved during the test. This is never a satisfactory method. Recommendations (section

1.111) are made that will remove this step in the test procedure.

The rod legs of the extensometer extended beyond the tubes only 1/4" in the original design. To handle the new gauges and the elongation of the test piece, the tubes were shortened so that the rods extend one inch.

After the gauges had been in operation for several hours they began sticking. This was caused by two factors, the lubricant becoming gummy and the use of the gauge in an inverted position.

The lubrication problem was easily solved by cleaning frequently and re-oiling with a very light machine oil.

The fact that the gauge was used in an inverted position meant that instead of the weight of the spindle acting in the same direction as the return spring, it opposed it. to overcome the sticking, the return spring was replaced with one about treble the spring constant.

The gauges in this condition are free from any tendency to stick if they are kept clean and frequently lubricated.

1.106 Resistance Thermometer.

The resistance thermometer supplied with the Sunvic RT 1 controllers, and called for in the specifications of the machine, consists of a non-inductively wound double helical coil in a slender fused silica tube. This arrangement is mechanically very fragile.

When, at the beginning of the construction stage of the furnaces, one of these thermometers was found to be damaged, it was decided to manufacture a thermometer with a more rugged type of construction.

The type of construction used resembled a mat. The platinum wire is passed through a series of fire clay insulators. This winding is shown diagramatically in figure 14. The winding is non-inductive so that changes in the furnace current will not affect the measurement of the resistance of the platinum. This thermometer has proved completely satisfactory.

1.107 Recording System.

The recording system (reference 3) used batteries to power the timers and cameras. This has the disadvantages of all battery powered systems. To overcome these, a rectifier was used to power these components. While the rectifier may not be any more efficient than the battery, it removes some of the causes for delay in the test programme and appreciably raised the morale of the author by eliminating these annoyances.

1.11 Recommendations.

1.111 Test Piece.

As previously mentioned, most of the difficulties associated with using these machines for S.G.C.I. emanate from the large amount of elongation of the test specimen. Since elongation is the product of unit elongation and gauge length, the obvious recommendation is to reduce the gauge length. It is recommended that the gauge length should be changed to two inches.

Although this new gauge length reduces the sensitivity of the extensometer to 0.00005 inches per inch this is still accurate enough for the class of testing proposed

1.112 Strain Take up Mechanism.

To overcome the need for constant attendance at the machine, it is recommended that a suitable automatic strain take-up mechanism be fitted to these machines.

The general arrangement of a proposed system is shown in figure 17. It consists, essentially, of two worm and wheel speed reducers, giving an over all gear ratio of 900:1. This high gear ratio was chosen to allow the use of a small electric motor to drive the straining rod extension. At full load it requires about twenty foot-pounds of torque to turn the hand wheel now fitted to the machines. With this gear ratio a one-fifth horse power motor will be adequate.

Since the worm and wheel on the straining rod extension

is moving slowly it is felt that the lubrication will pose no problem. However, if the one attached to the motor gives rise to lubrication problems, it can easily be enclosed in a case to provide for more through protection.

The take up of strain will be controlled by limit switches actuated by the position of the main loading lever.

1.113 Recording camera.

Although the photographic recording of test data was on the whole usable, it did on many occasions leave much to be desired. It is felt that the replacement of the present cameras by one designed for recording data would be advantageous.

1.114 Temperature Controller

Temperature control in these tests was 2°C. This is not accurate enough to make the creep data reproducable. Gillet and Cross (reference 4) have published data that shows that a 3°C. variation of temperature at 371°C. can cause a creep life of 10 years to be read as $4\frac{1}{2}$ or 23 years, depending on the direction of the error. Lomas, Jepson and Rait (reference 6) have published results of investigations with proportional controllers that have given remarkable accuracy of temperature control (less than 0.1°C. at 900°C).

It is recommended that the use of this type of controller be investigated, if it is desired to increase the reproducability of the results.

Part 2

Creep Test Procedure.

CREEP TEST PROCEDURE

2.1 Assembly.

The first step in assembling the test specimen is to coat the spherical collar with graphite in the form of a colloidal dispersion. The graphite is applied to all the mating surfaces and threads of this assembly. This coating of graphite aids in loading the test specimen axially by lubricating the spherical seat. In addition it helps prevent the parts of the assembly from adhering to each other, thus facilitating disassembly at the end of each test. The collar is then placed in the spherical nut and the end of test piece threaded into the collar. After both collars have been assembled on the test piece the straining rods are inserted into the nuts.

With the straining rods, nuts and collar assembled, the thermocouples are attached. These thermocouples are affixed to the test piece by a single turn of nickel wire. They are then covered with asbestos string to prevent the developed E.M.F. from being affected by direct radiation from the furnace walls.

The rod portion of the extensometer is then assembled on the upper end of the test piece. The extensometer clamps on the threaded portion of the test specimen. It should be kept as close to the end of this thread as possible. The tube portion of the extensometer is then assembled on the lower end of the test piece. A check should be made

to ensure that there is approximately one inch of the rod extending beyond the tube end. Failure to have this length will cause the spindle of the dial gauge to foul on the end of the tube. Before fully securing the extensometer the alignment between the axis of the test piece and the extensometer legs should be checked.

The gauges are then attached to the tube legs of the extensometer by means of small chucks (figure 9).

The completed assembly is shown in figure 12.

The assembly is then inserted in the machine. A slight load is then applied to the test piece. The furnace openings are then packed loosely with asbestos wool. The procedure is necessary, because if the specimen is unloaded when the openings are packed or the openings packed too tightly the furnace applies a sidewise force on the assembled test piece. This makes it practically impossible to load the specimen axially.

With the ends packed with asbestos, the thermocouples are attached and the furnace and controller switched on.

2.2 Heating and Soaking.

Reference (1) requires that the test piece be brought up to temperature in four to six hours. The settings of the Variac, rheostats and controllers when set for 450°C. will cause the specimen to attain the test temperature in the required interval.

After attaining the test temperature, the specimen should be held at the test temperature for twenty to twenty-four hours. This is to ensure uniformity of temperature over the test piece.

2.3 Loading.

After the test piece has been "soaked" for the required length of time, it is ready for loading. A small initial load is applied by lowering the lever support yoke. This load should produce a deflection of approximately ten divisions (0.001") on the dial gauges. The gauges should be checked before and after the load is applied. If the extensions shown on both gauges are within two divisions (0.0002") a further load is applied to produce another ten divisions of deflection. If this second load produces the same elongation the specimen is assumed to be axially loaded.

If the first load does not produce deflections within the two divisions prescribed, the load is removed and the lateral position of the straining rods is adjusted and the load reapplied and checked.

When it has been determined that the test specimen is axially loaded, the lever support yoke is lowered until the test specimen has taken the entire load. Simultaneously the hour meter and the recording system are turned on.

2.4 Automatic Recording.

The procedure recommended for recording the elongation and the time is to photograph the loading continuously. From this record it is possible to determine the initial extension of the test piece. After the load has been applied the timer is set for short intervals while the test piece is in the primary stage of creep. When the rate of extension becomes smaller the interval is increased. In the longer tests (50 to 300 hours) the four hour clock is used and in the medium length tests (10 to 50 hours) the fifteen minute clock was found to be the most satisfactory.

During the test, visual readings were taken to ensure the maintenance of temperature, the axiality of loading and to serve as a comparison with the photographic record.

Part 3

Spheroidal Graphite Cast Iron.

SPHEROIDAL GRAPHITE CAST IRON

3.1 General.

In 1947, the production in our foundries of spheroidal graphite cast iron began. This added to the available list a new range of materials which combine the advantages of cast iron with much of the strength and toughness of steel.

For a very long time, grey cast iron has been one of the important engineering materials. It is easily cast into intricate shapes. It is rigid. It has a useful resistance to corrosion. However, it is weak and brittle.

The microstructure of grey cast iron readily shows the causes for this weakness and brittleness. It has a matrix of ferrite or ferrite and pearlite with the graphite in flakes. These flakes are devoid of any strength. In addition, they act as sharp edge cracks, that are serious stress raisers.

If the carbon is burned out prior to casting, thus converting the cast iron to a steel, the effects of the flakes will be removed. This, however, is at the expense of good casting characteristics, cheapness and other desirable features..

The ideal cast iron would maintain the 3 to 3½% carbon, for good casting properties, but would have the graphite

in small spheres, thus minimising any stress raising tendency.

An approach to this was made in the development of malleable cast iron. By means of a very long, and consequently costly, heat treatment cycle, the graphite comes out as a nodule. Sometimes these nodules are spheres and sometimes they are groups of small flakes. Some effects of the graphite flakes are removed and malleable iron is stronger and very much more ductile than grey cast iron. However it is very costly. Further, the technique is limited to those small sections that can be chilled to produce a white cast iron.

In the late forties, it was found that the addition of a small amount of cerium to cast iron would cause the graphite to come out of solution as spheres. Later, in 1948, it was found that magnesium had the same result. This new material has been called nodular iron, ductile iron, nodular graphite cast iron, ductile cast iron, or spheroidal graphite cast iron. The latter is the most technically accurate name and is coming into general use.

In general, S.G.C.I. is used in two forms, classified according to the structure of the matrix. Sections of ½ to 2 inches will normally give a pearlitic matrix. Sections less than ½ inch or sections that are quickly cooled tend to give white iron structure, with most of the

carbon combined. This produces a very hard white cast iron.

Both the pearlitic and white S.G.C.I. can be annealed at 900°C. for several hours, and then slowly cooled. This produces a ferritic matrix (figure 15). The tensile strength is reduced but the elongation is increased remarkably.

In sections larger than 2 inches the matrix will be a mixture of the pearlitic and ferritic types (figure 16).

A summary of the typical mechanical properties at room temperature is given in table II. The corresponding properties of high-duty flake graphite cast iron are included for comparison.

3.2 Manufacture of S.G.C.I. for Development Programme

This iron was made in an oil fired tilting crucible furnace. The charge was as follows:

59 kg of Warner S.P.H. refined iron

21 kg of Swedish white iron.

This charge was melted down under charcoal and superheated to 1450°C. The melt was then skimmed and one kilogram (1.25%) of a 15% magnesium nickel alloy added to the surface. The iron was well stirred and inoculated with 0.5% silicon added as 625 grammes of ferrosilicon containing 80% silicon. The melt was well stirred again

and skimmed before casting into nine green sand clover-leaf moulds. These were marked ZWD 1 to ZWD 9 in the order of pouring.

All of the bars were annealed for two hours at 900°C and then transferred to a furnace at 700°C and held at this temperature for 24 hours before air cooling. The longer than usual soaking period at 700°C was adopted to ensure a fully ferritic matrix structure. (Figure 15)

3.3 Micro Structure.

Microscopic examination showed that 95% of the graphite of the bars was in the spheroidal form, the balance being compacted graphite with very small amounts of compacted flake graphite. The matrix structures consisted of ferrite with up to 2% residual spheroidized pearlite.

3.4 Chemical Analysis.

An analysis of the first and last bars cast is given below.

Mark	C	Si	Mn	S	P	Ni	Mg
ZWD 1	3.4%	2.1%	0.2%	.005%	.030%	1.15%	.062%
ZWD 9	3.3%	2.1%	0.2%	.009%	.025%	1.15%	.056%

The balance is, of course, iron.

3.5 Mechanical Properties.

The results of duplicate tensile and impact tests on

samples from ZWD 1 and ZWD 9 are as follows:

Mark	Yield (t.s.i)	U.T.S. (t.s.i)	Elong.on 2" (%)	L.of A. (%)	Impact ft.lb.
ZWD 1	22.6	29.0	21.5	22.8	92
"	23.2	29.3	20.5	25.6	103
ZWD 9	21.4	28.3	22.5	24.8	90
"	20.5	28.8	22.5	27.5	92

The tensile tests were carried out on test bars 0.564" in diameter and the impact tests on unnotched bars 0.450" in diameter.

3.6 Creep testing programme

In all, some twenty-one tests were carried out in the development of these machines. A record of the tests and the results are given in the appendix 1. A summary of available data at elevated temperature is given in appendix 2.

The data included should be subject to confirmation due to the limited amount of testing and the difficulties of testing during a development programme.

In creep testing, there is a wide variation, from test to test, under supposedly the same conditions. There are actually several so far uncontrolled variables.

The loading is supposed to be, to quote the specification, " as axial as is possible", but there are bound to be variances from one test to another. This difference in eccentricity of loading will produce stresses different from that calculated from area and load and therefore different creep data.

The effect of variation of temperature has already been discussed (section 1.114).

Variation in material from one test to the other may lead to scatter in the results. This is particularly true with the heterogeneous structure present in S.G.C.I.

Consequent to the above discussion it will be necessary to improve the control of these variables to eliminate their effect, or to base the test on a broad statistical basis to evaluate the effect of these random variations.

3.7 Mechanism of Failure.

The fractured specimens were examined visually upon removal from the machines at the end of a test. In all cases a definite roughness (figures 18 and 21) was noted about the fracture area. At first thought, this was laid to a scaling phenomena, but, when test pieces remained in the furnace for the limiting time of the tests (300 hours) without any visible signs of this roughness, it was decided to examine the fractures more carefully.

A macroscopic examination revealed that this roughness was due to small cracks on the surface surrounding the failures. On several occasions a well developed crack was found well removed from the fracture. On one occasion when an unbroken test piece was removed from the furnace at 300 hours it was found to have cracks visible to the naked eye (figures 20 and 21).

A microscopic examination of the fractured surface (figure 22) shows an additional crack about a 1/16" from the fracture. This figure and figure 23 show that the failure is intergranular and proceeds from one spheroid of graphite to another.

Since the fracture of the test piece develops from a crack that originates in one of the stress-raising graphite spheres on the surface (figure 20) some surface treatment that would remove the graphite on the surface should improve

the over all creep strength. This would leave a surface with the strength of the matrix which should be about 40-45 t.s.i.

Orowan (reference 7) has proposed that the terciary stage in creep is not, in reality, a change in the creep rate, but a change in the level of stress due to stress raisers. The examination of the fractures and cracks in S.G.C.I. is seen to support this.

Part 4

Conclusions.

Conclusions.

4.1

The machines, as modified, are capable of creep testing S.G.C.I. Certain further modifications have been recommended to improve the testing procedure.

4.2

Spheroidal graphite cast iron can support 10 t.s.i. for 300 hours without failure at 450°C.

4.3

Failure is intergranular and proceeds from one spheroid of graphite to another.

4.4

Some form of surface treatment to remove the graphite near the surface should improve the creep strength of spheroidal graphite cast iron.

References.

1. British Standard Specification 1687 Part II.
2. British Standard Specification 1610.
3. Rippon .M. Thesis of College of Aeronautics, June 1953.
4. Everest, A.B. "Engineering Properties and Applications of Spheroidal Graphite Cast Iron." 4th Intern.Engg.Congress, Stockholm, June 1952.
5. Gillet, H. W. and Cross, H.C. Metals and Alloys 1933, Vol.4 pp. 91-98.
6. Lomas, T.W, Jepson, M.D., and Rait, J.R. Journal of the Iron and Steel Institute, Vol.168, June 1951, pp.126-134.
7. Orowan, E. Proceedings of First U.S.National Congress of Applied Mechanics, June 1951.

Tables

Table I

Calibration of Weights.

Weight Number	Force on Test Piece (lb)	Stress on 0.1 sq.in. (t.s.i.)
Beam and Weight pan	119	0.446
1	55.5	0.248
2	55.5	0.248
3	55.5	0.248
4	55.5	0.248
5	104.5	0.467
6	104.5	0.467
7	206.5	0.923
8	205.5	0.917
9	207	0.925
10	206	0.920
11	205.5	0.917
12	205.5	0.917
13	205.5	0.917
14	206	0.920
15	206	0.920
16	206	0.920
17	207	0.925
18	204	0.911
19	205	0.916
20	204.5	0.914

Table I continued...

Weight Number	Force on Test Piece (lb)	Stress on 0.1 sq.in. (t.s.i.)
21	205	0.916
22	205	0.916
23	205	0.916
24	205	0.916
25	205.5	0.917
26	206.5	0.922
27	206	0.920
29	205.5	0.917

Note: There is no weight numbered 28.

Table II

Summary of Mechanical Properties of High Duty Cast Iron and Spheroidal Graphite Cast Iron.

Property	Hi-duty Iron	S.G.C.I.	
		As cast	Annealed
U.T.S. (t.s.i.)	18-22	35-45	27-35
Yield (t.s.i.)	-	25-35	20-25
Elongation (%)	Nil	1-5	10-25
Compressive strength (t.s.i.)	60-65	65-80	48-58
Compressive Yield strength (t.s.i.)	-	32-40	24-32
Elastic Modulus (millions of p.s.i.)	18	25	25

Figures

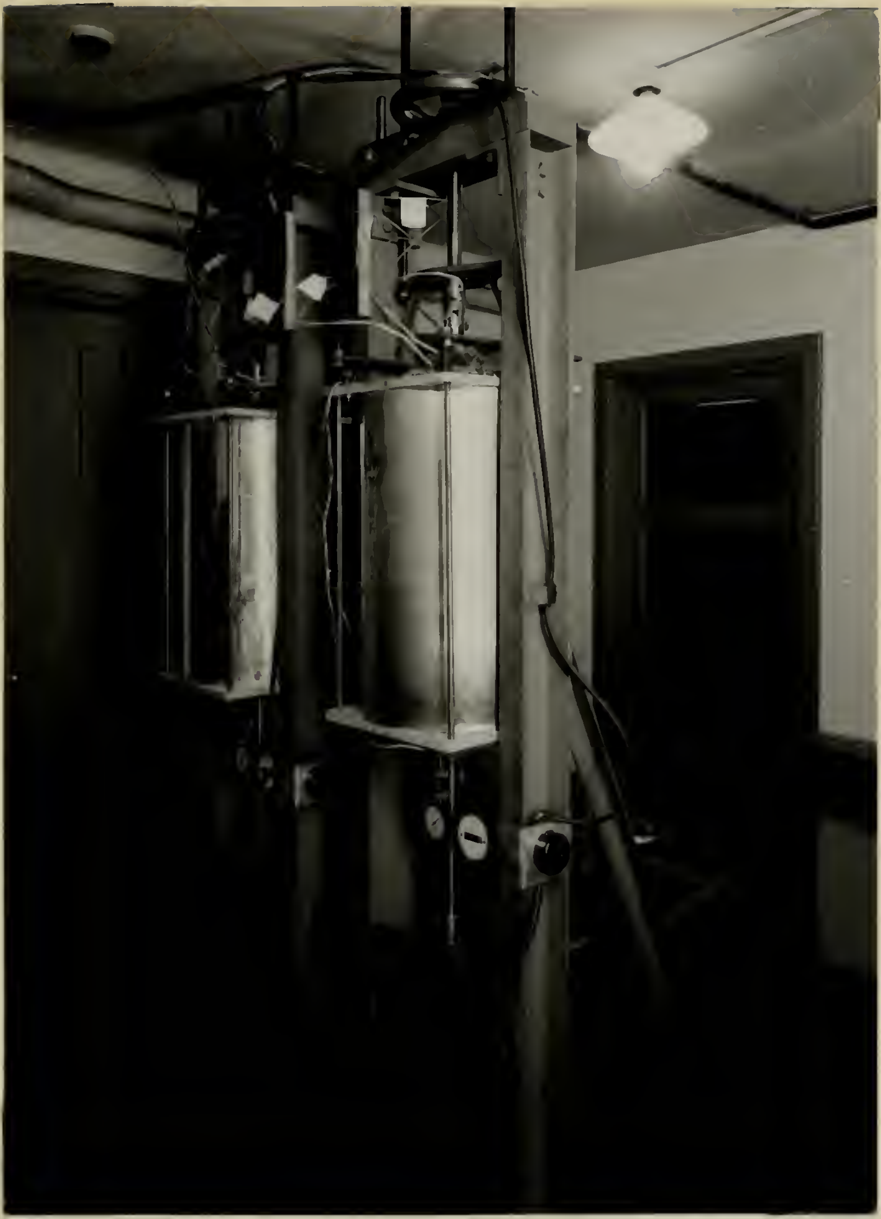


Figure 1

Creep Testing Machines
Front view

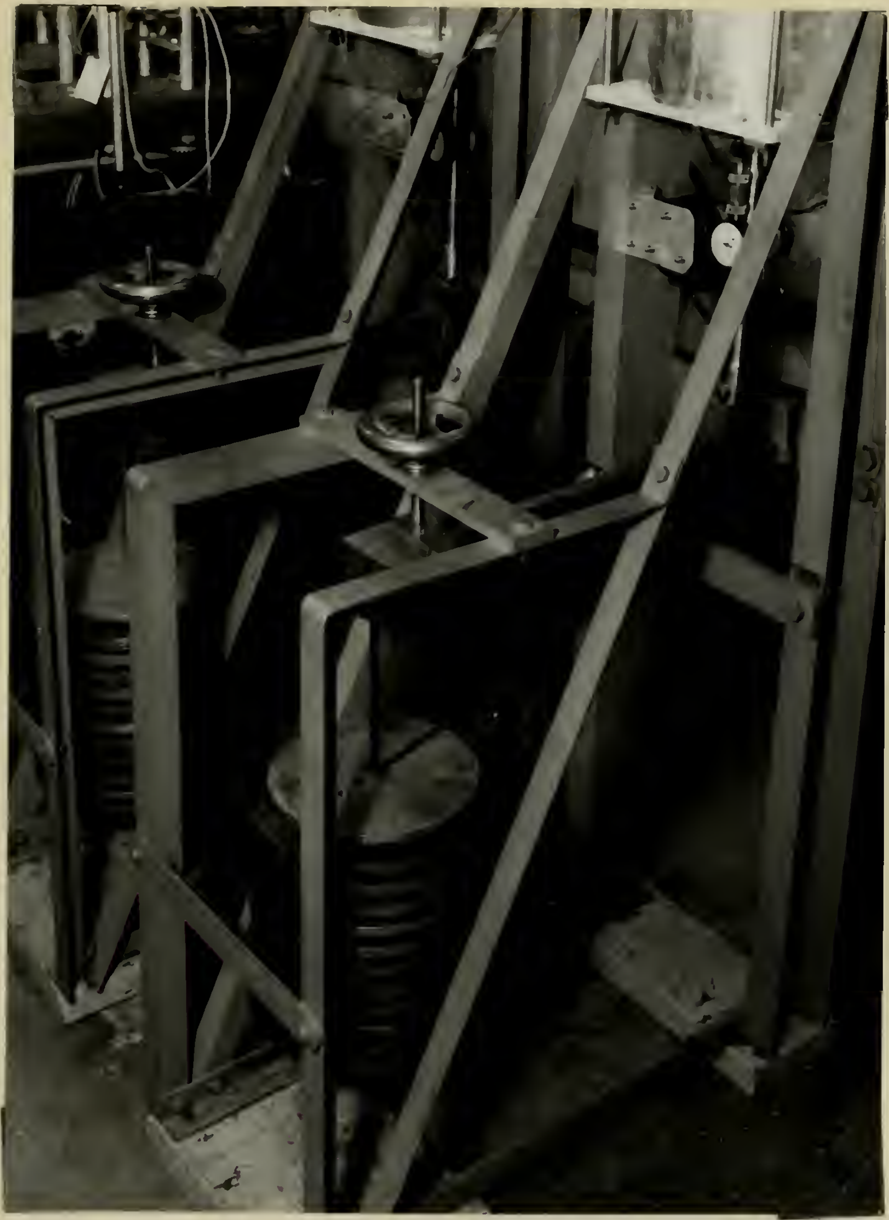


Figure 2
Creep Testing Machines,
Showing loading system

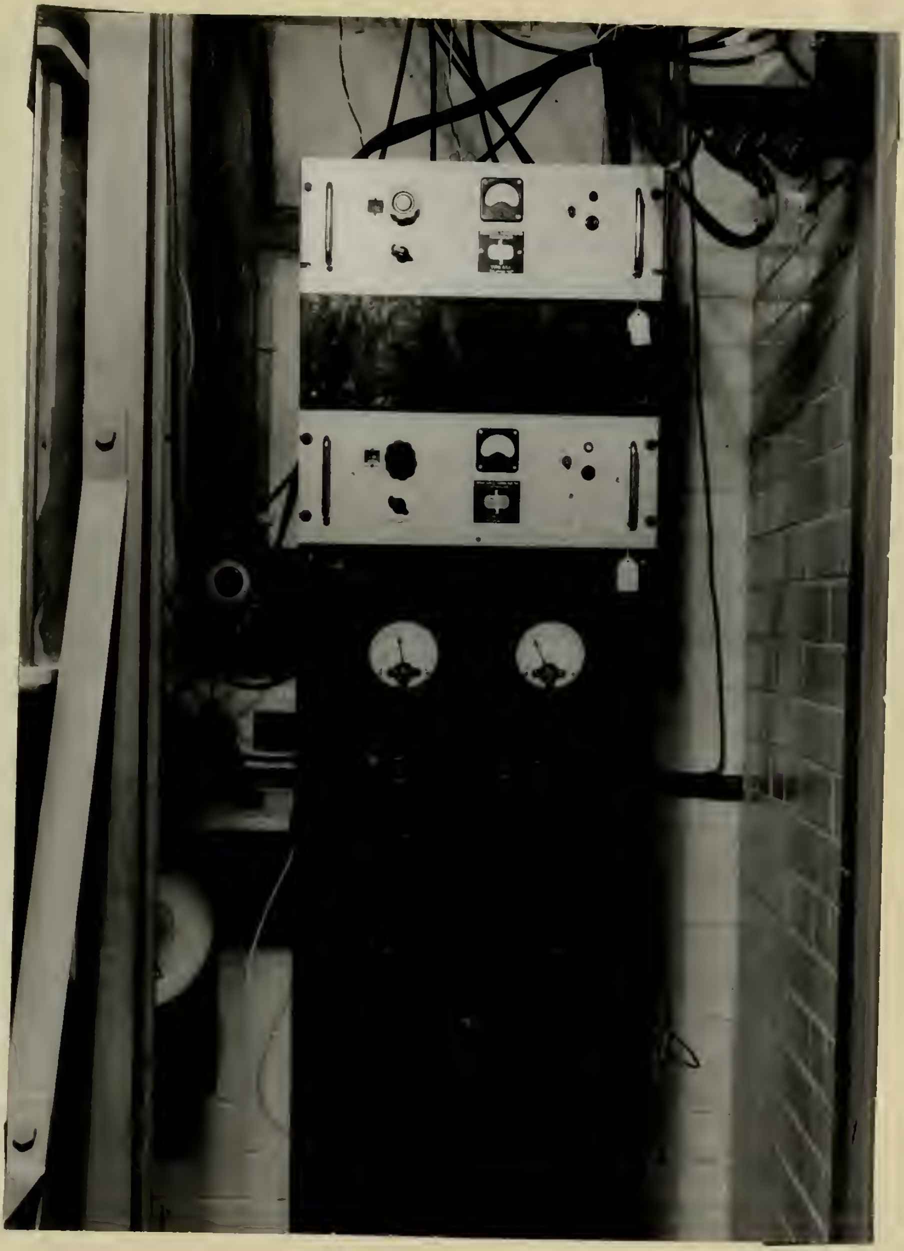


Figure 3

Control Panel

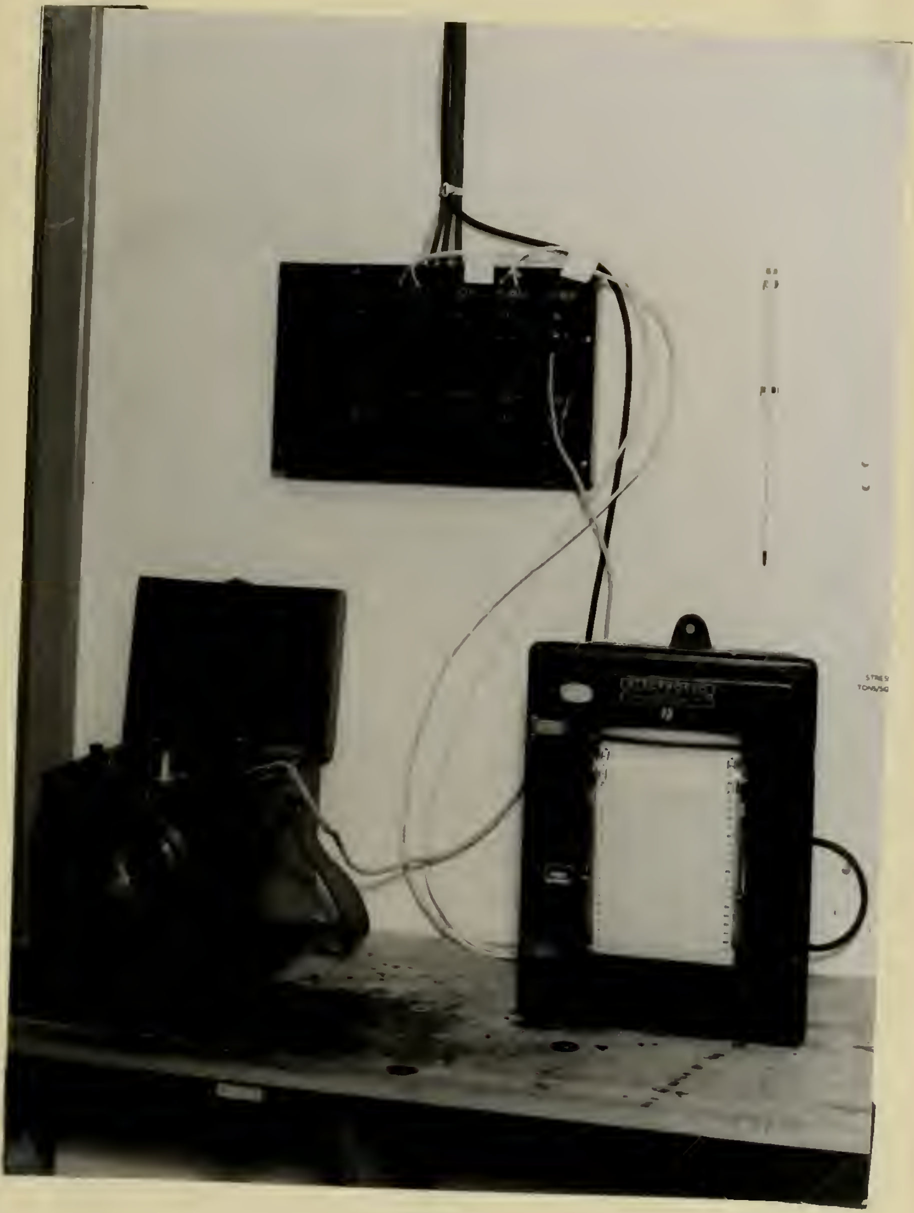
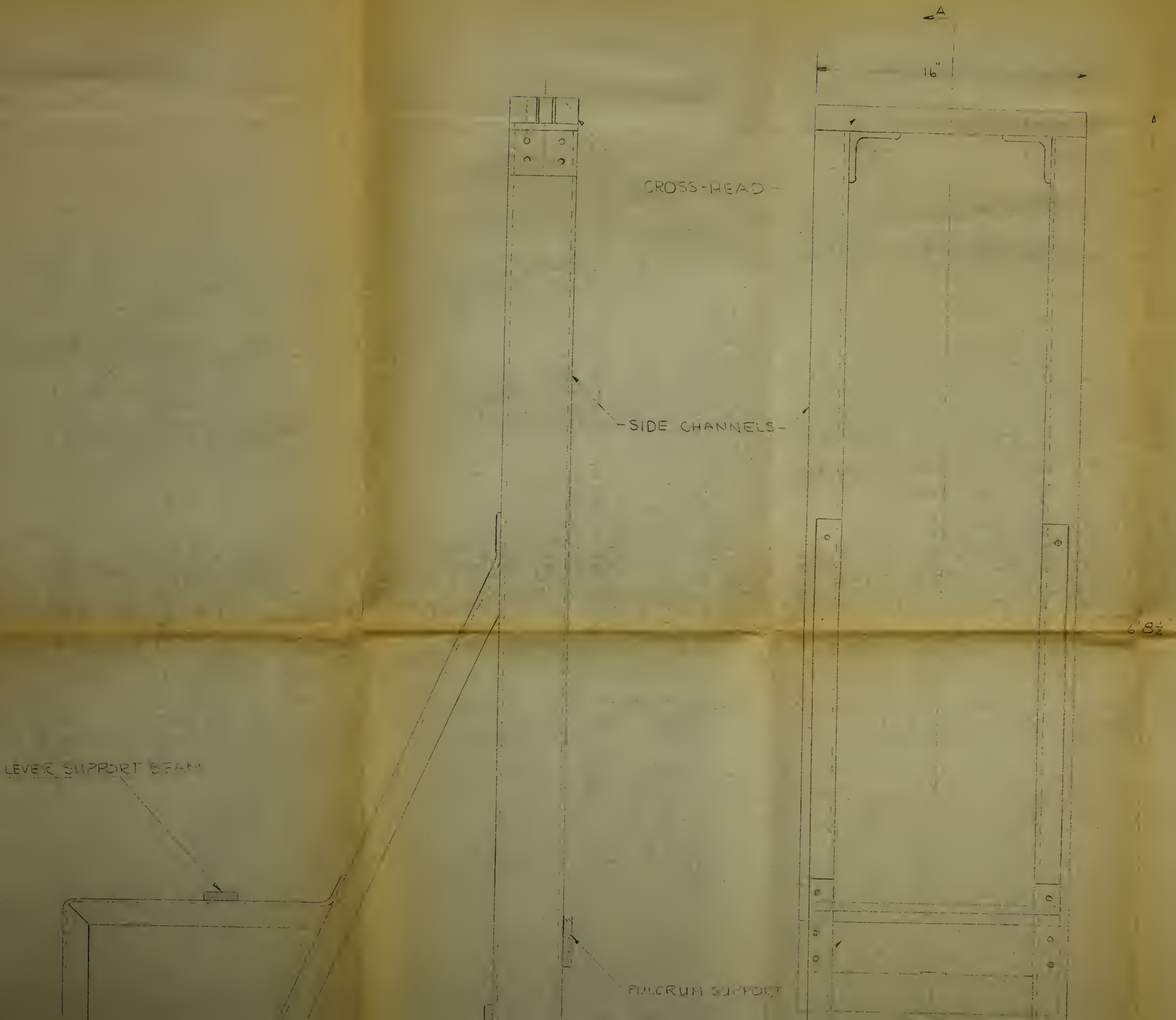


Figure 4

Temperature Measuring Station,
showing thermocouple board, top,
potentiometer, left, and recorder, right


A
16"
CROSS-HEAD
SIDE CHANNELS
6'8½"
LEVER SUPPORT BEAM
FULCRUM SUPPORT

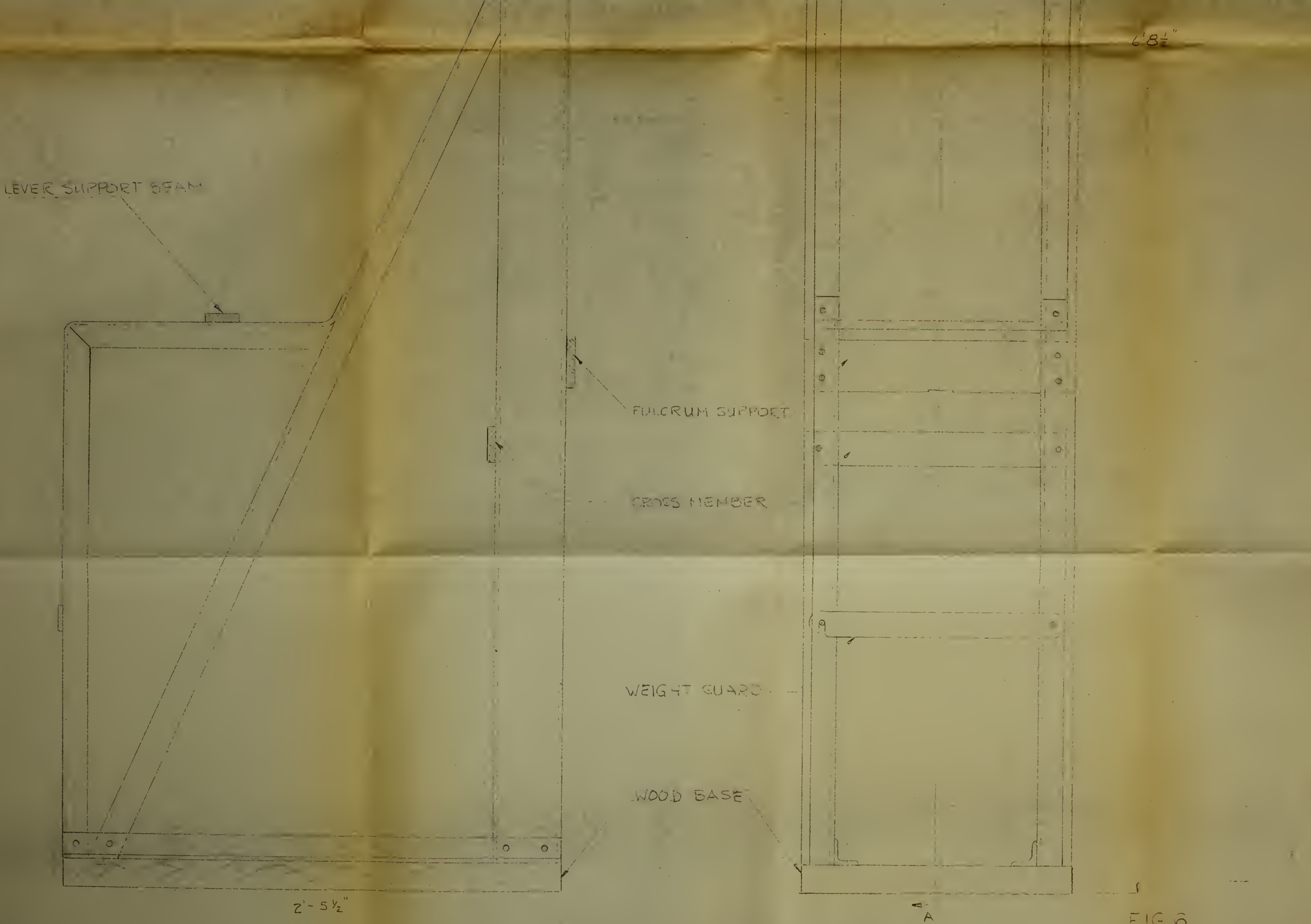


FIG. 6
MACHINE FRAME

SECT A-A

FIG 7
FURNACE

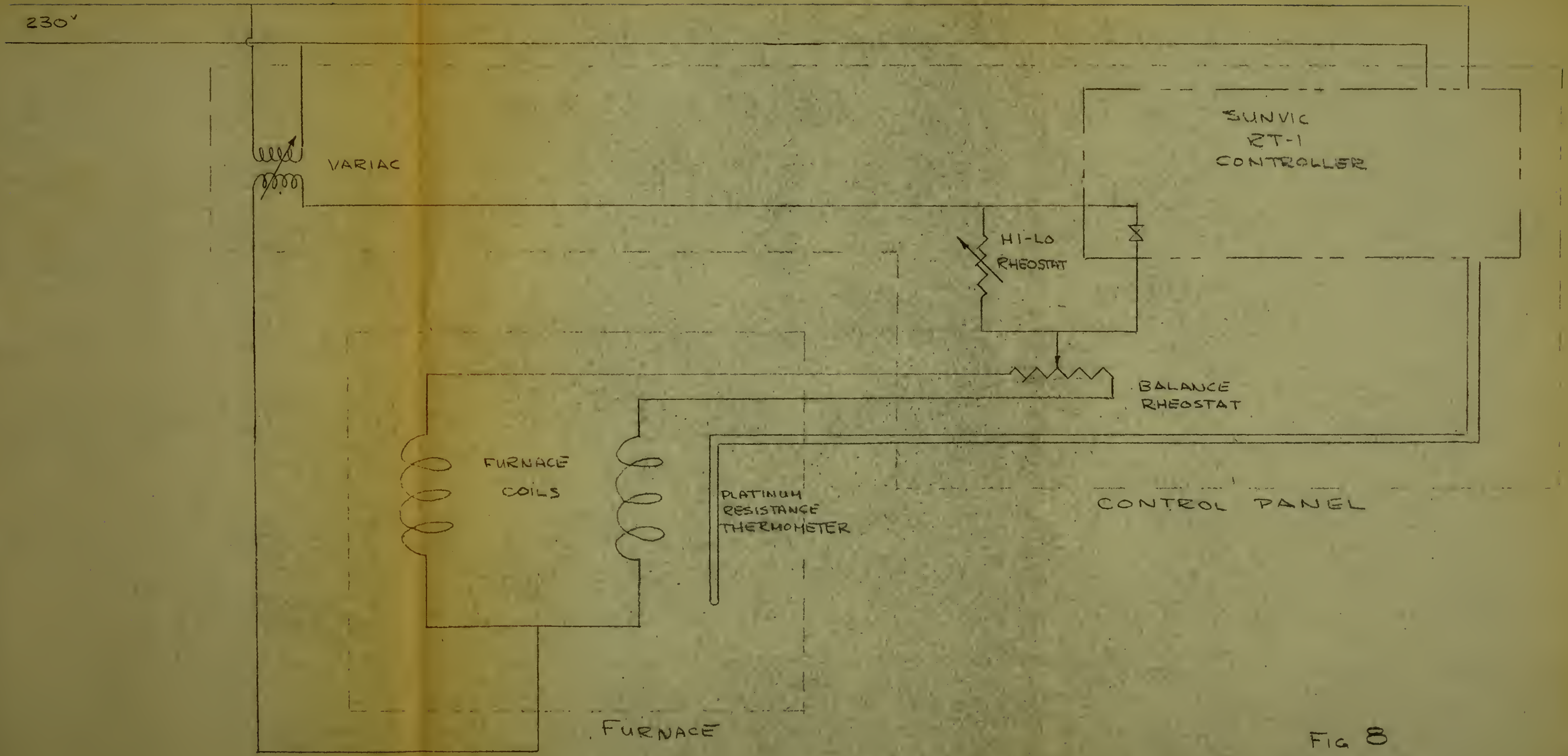


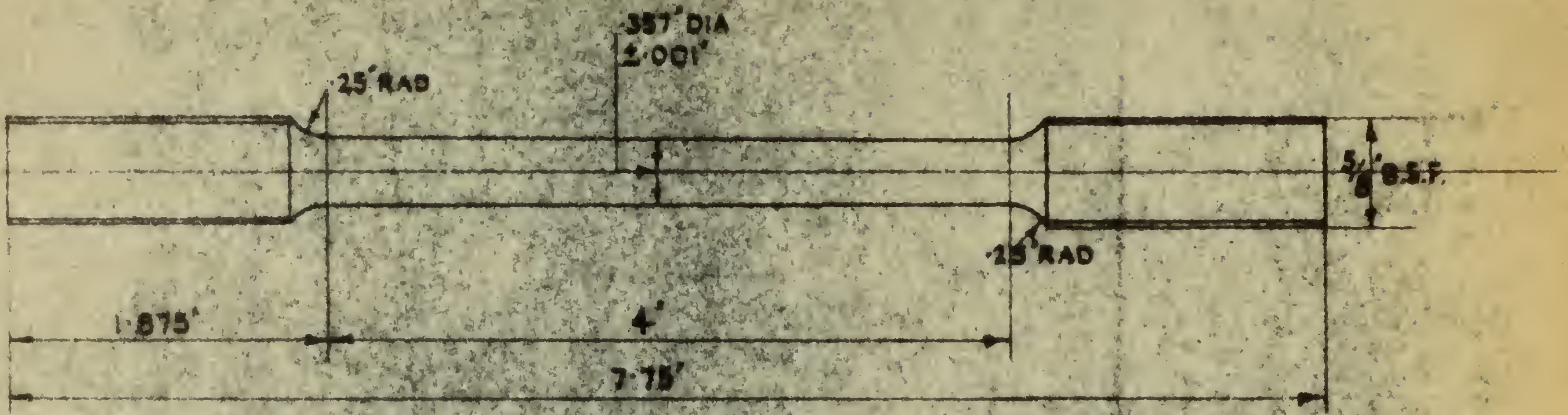
Fig 8

Schematic

Wiring Diagram.

Fig 9.

Extensometer Assembly



TEST PIECES TO BE GROUND & POLISHED TO A SUPERFINE FINISH, FREE FROM SCRATCHES & SCORES. PARALLEL PORTION TO BE ROUND & TRULY CONCENTRIC WITH SCREWED ENDS.

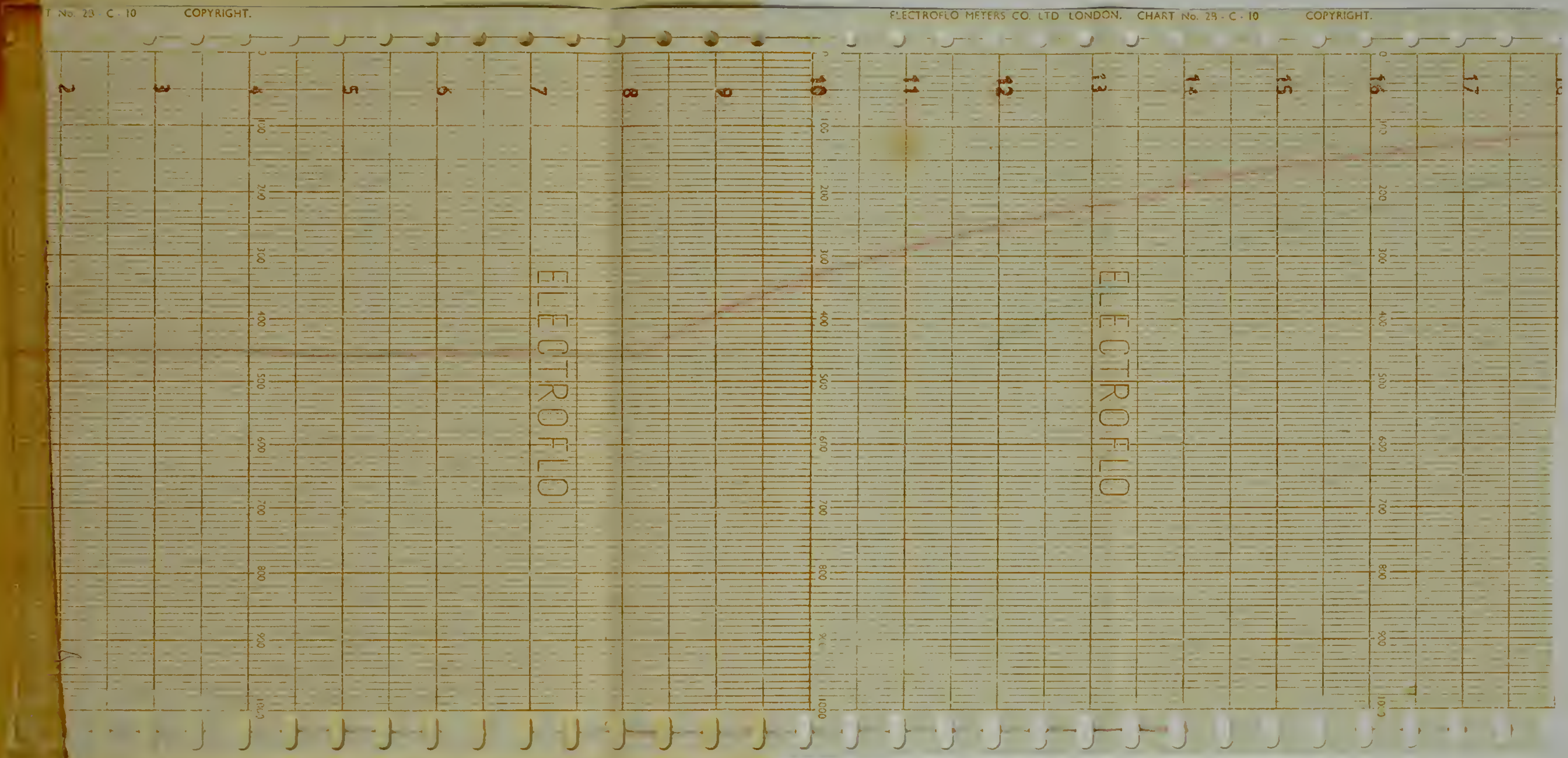


Figure 11

Temperature Recorder Chart.

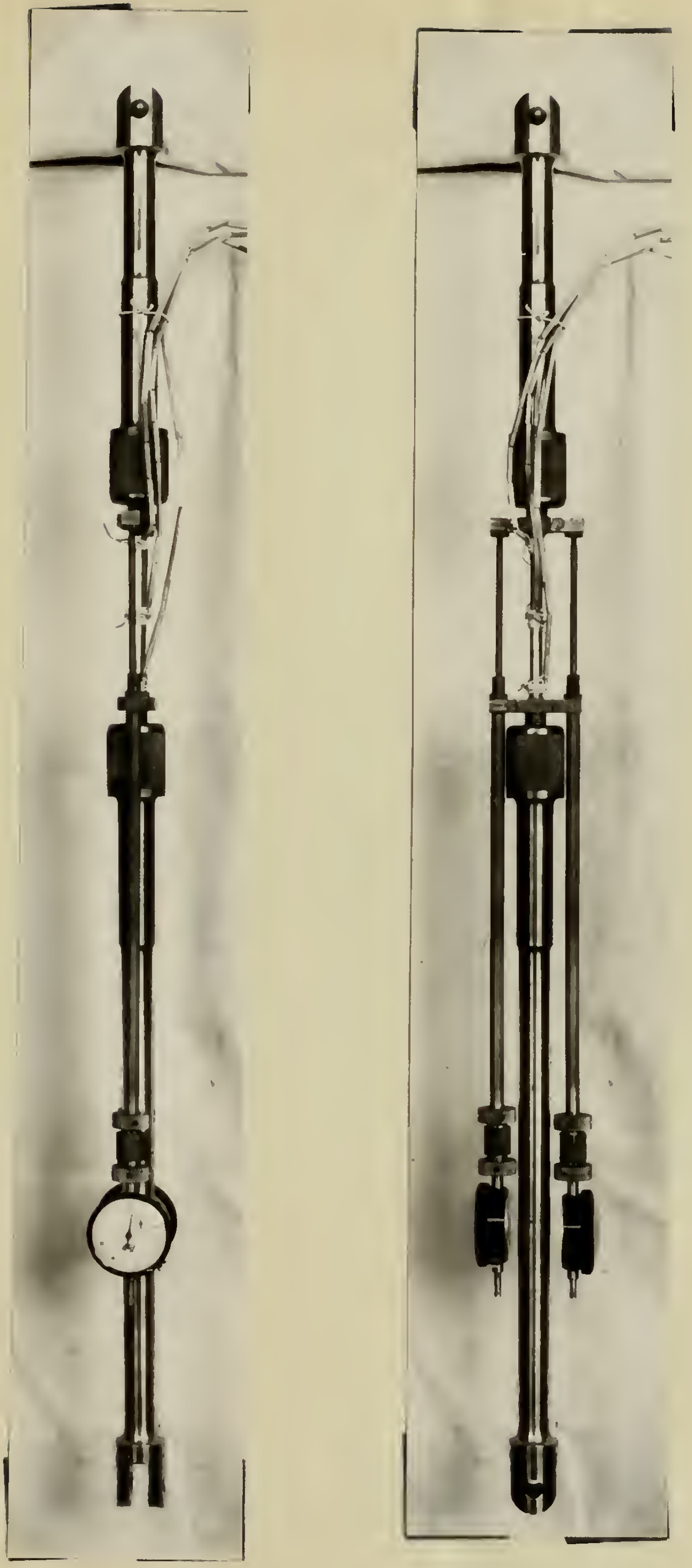
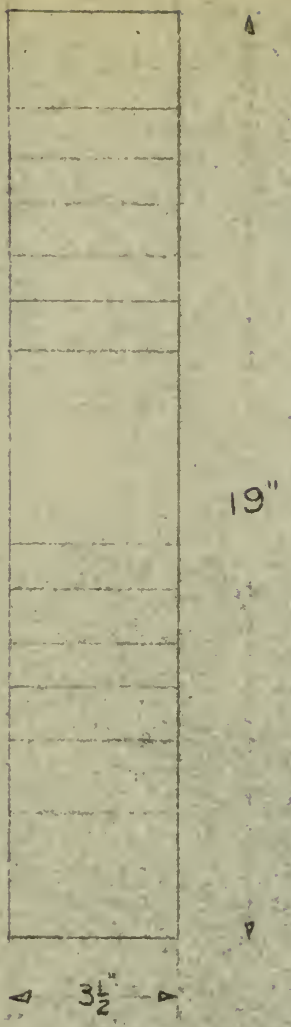


Figure 12

Assembled Test Piece
and Straining Rods



INCHES	TURNS
2	—
1	6
1	6
1	7
1	7
1	6
4	—
1	6
1	7
1	7
1	7
1½	9
2½	—

FIG. 13
FURNACE WINDING SPACING.

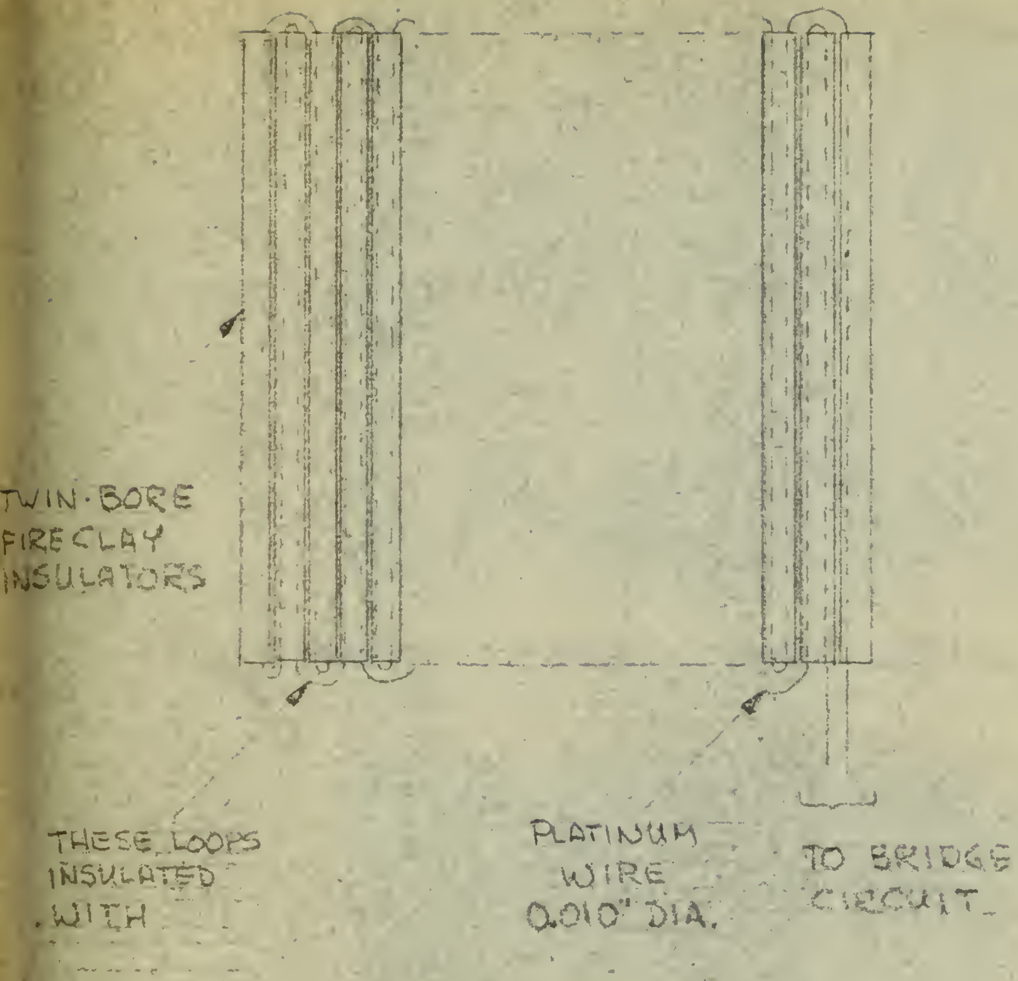
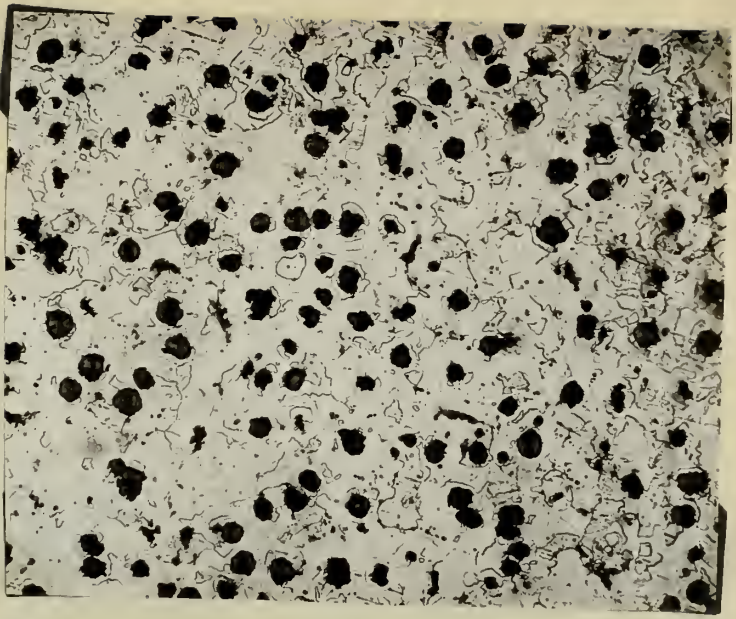
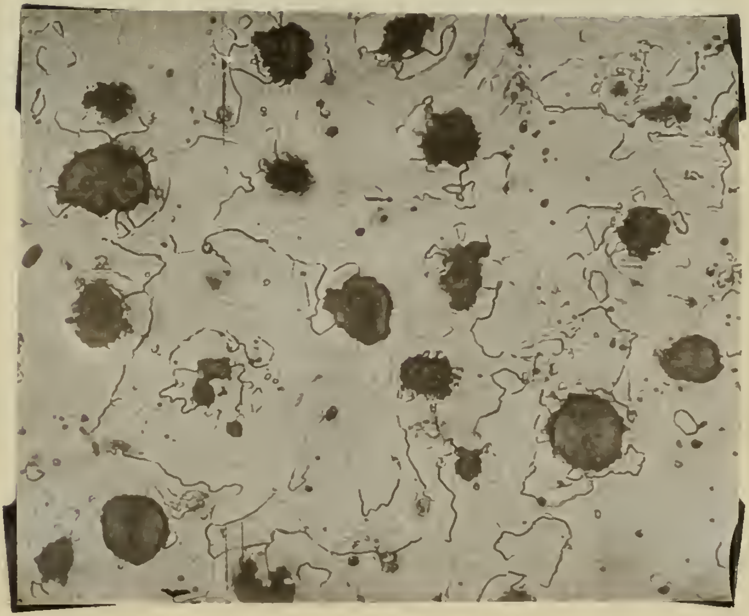


FIG. 14

RESISTANCE
THERMOMETER



(a) x 50 Etched in 2% Nitric acid in alcohol.



(b) x 150 Etched in 2% Nitric acid in alcohol.

Figure 15

Fully annealed spheroidal cast iron
showing ferritic matrix.

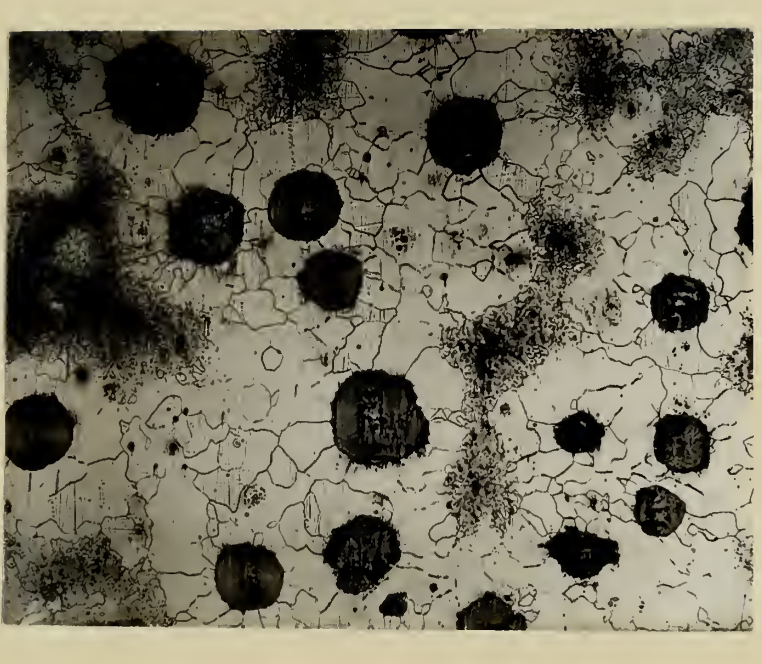
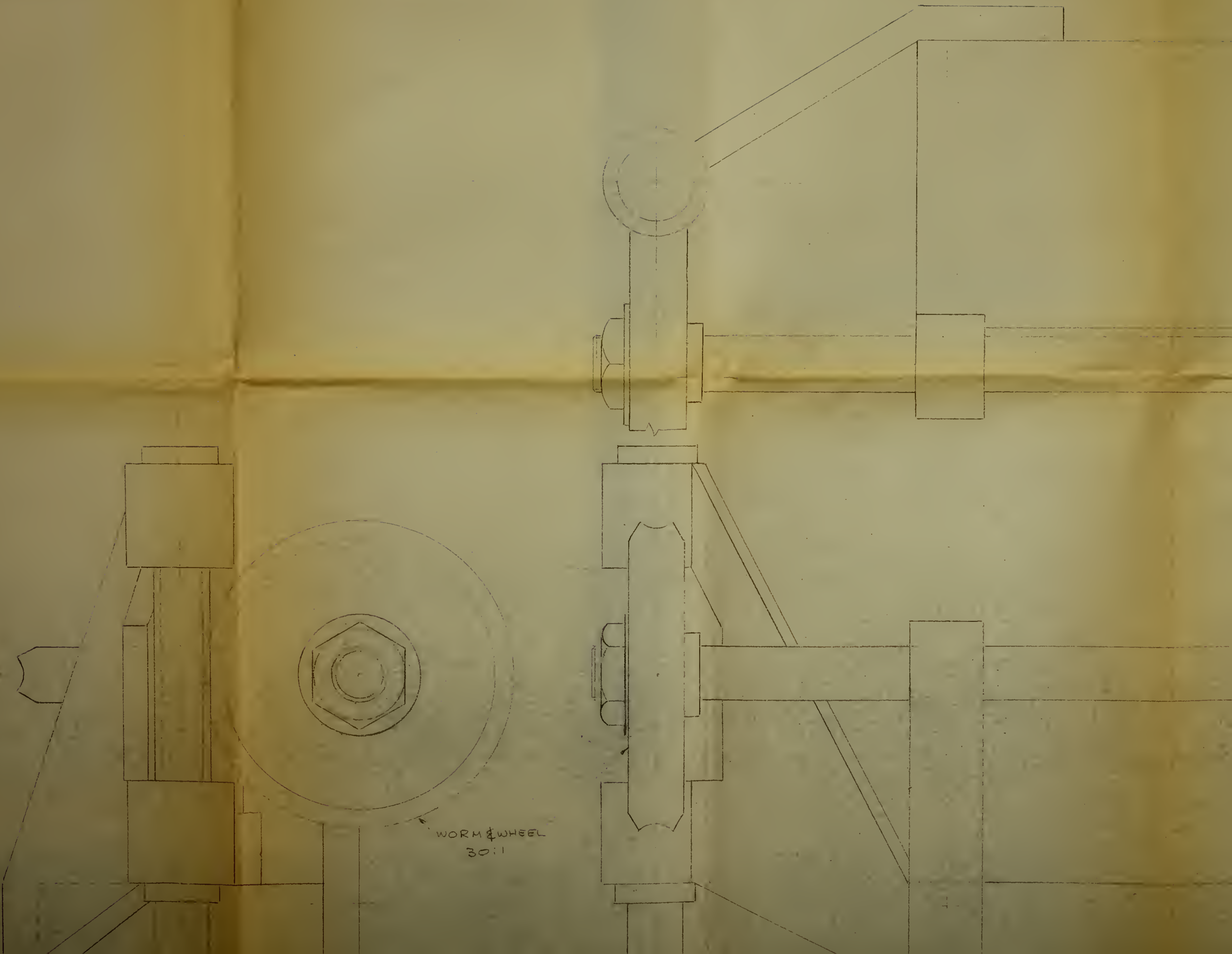
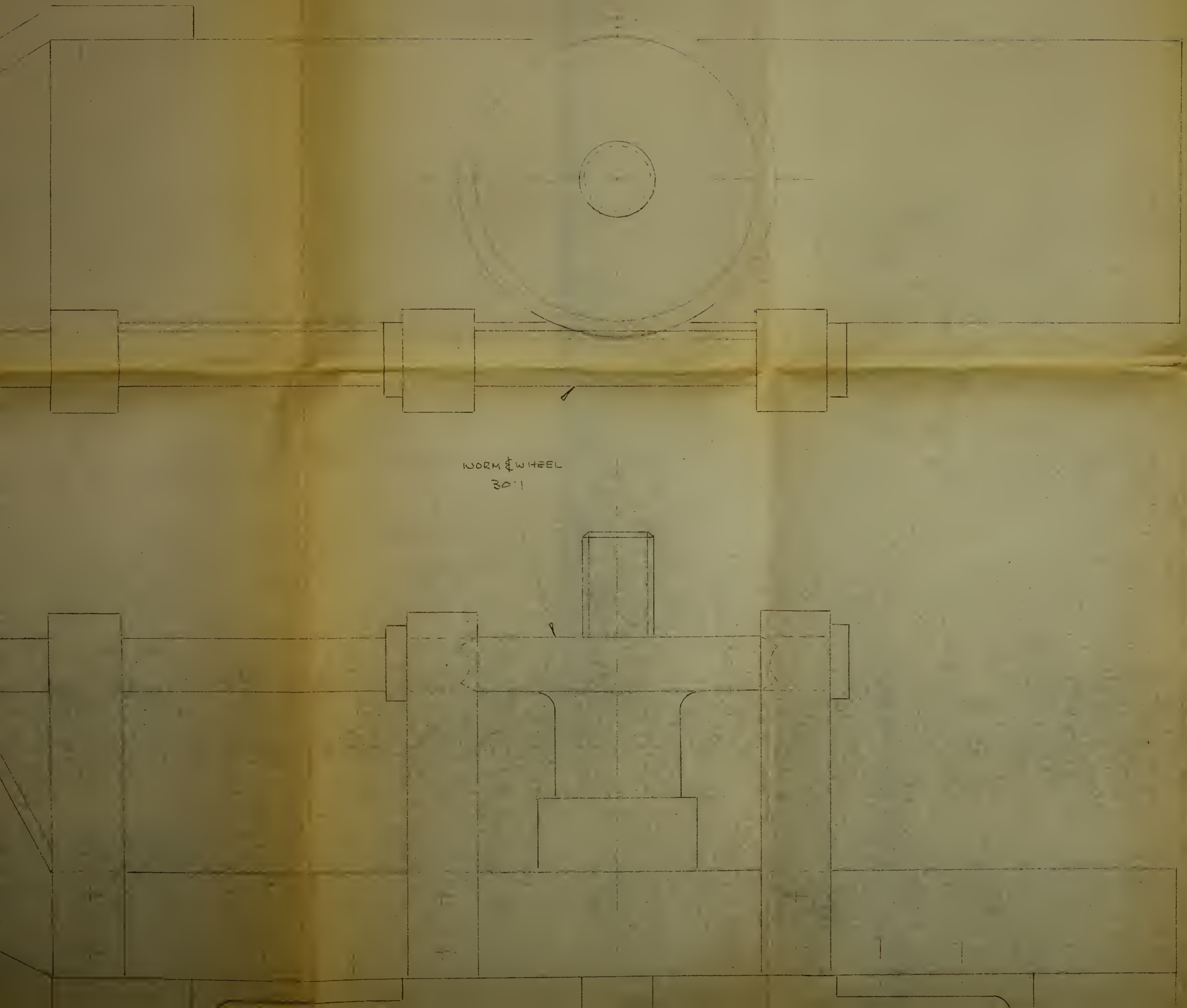
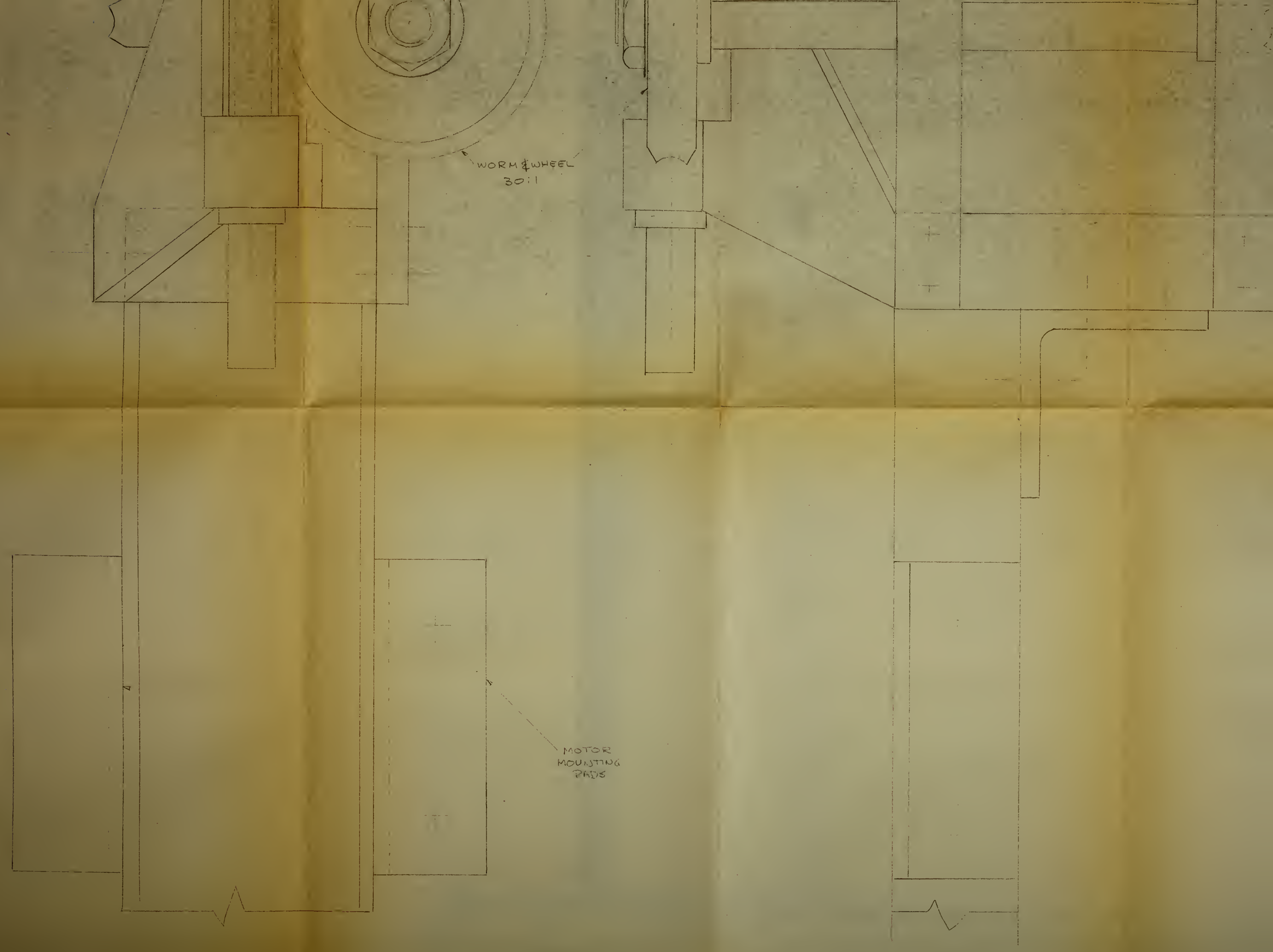


Fig 16

Partially Annealed S.G.C.I.
Showing a matrix of mixed
ferrite and pearlite.


WORM & WHEEL
30:1


WORM & WHEEL
30:1


WORM & WHEEL
30:1
MOTOR
MOUNTING
PADS

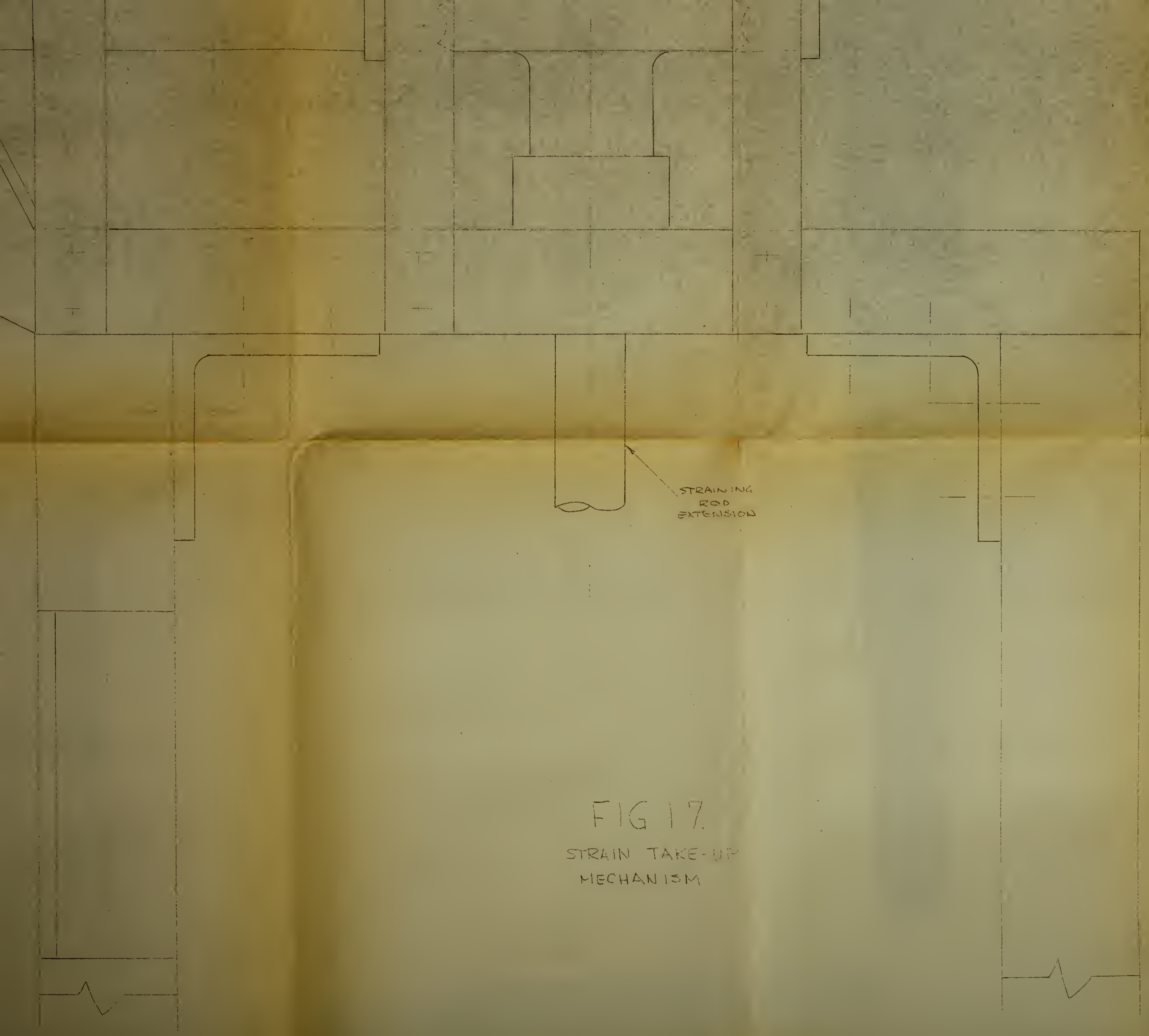


FIG 17.
STRAIN TAKE-UP
MECHANISM

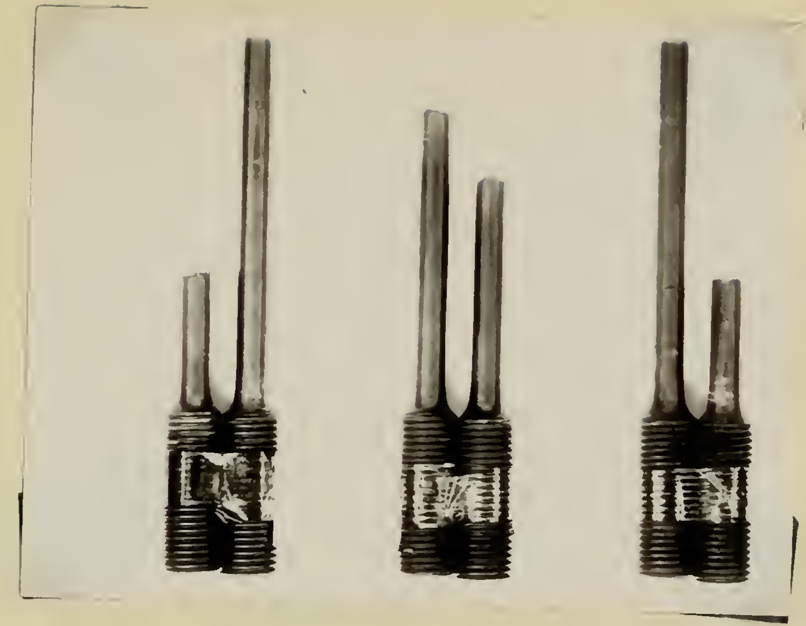


Figure 18.

Typical Fractures.

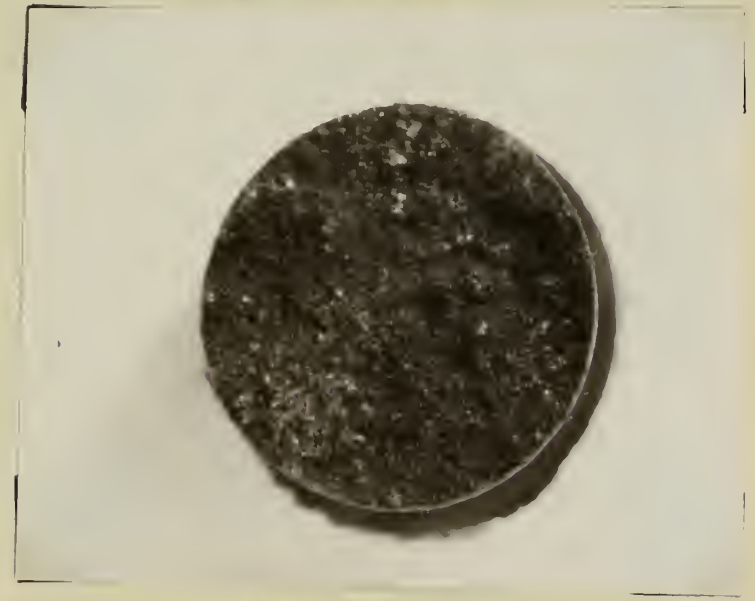


Figure 19.

Fracture Surface.

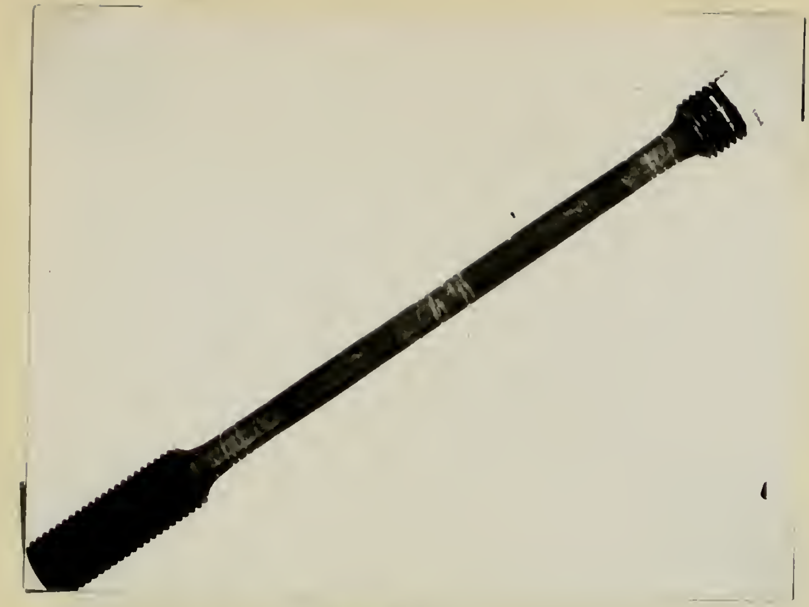


Figure 20.

Cracked specimen. Cracks near centre and at lower left.

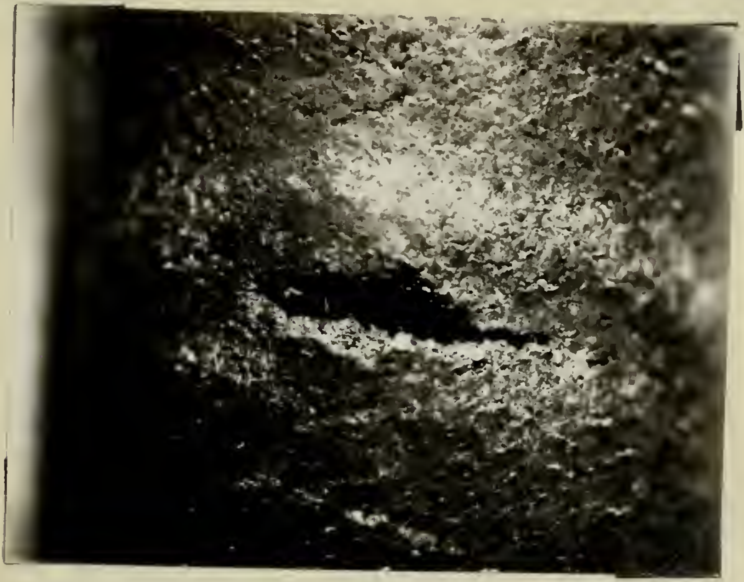


Figure 21.

Crack at centre of figure 20 magnified (x 10) showing rough area surrounding crack.

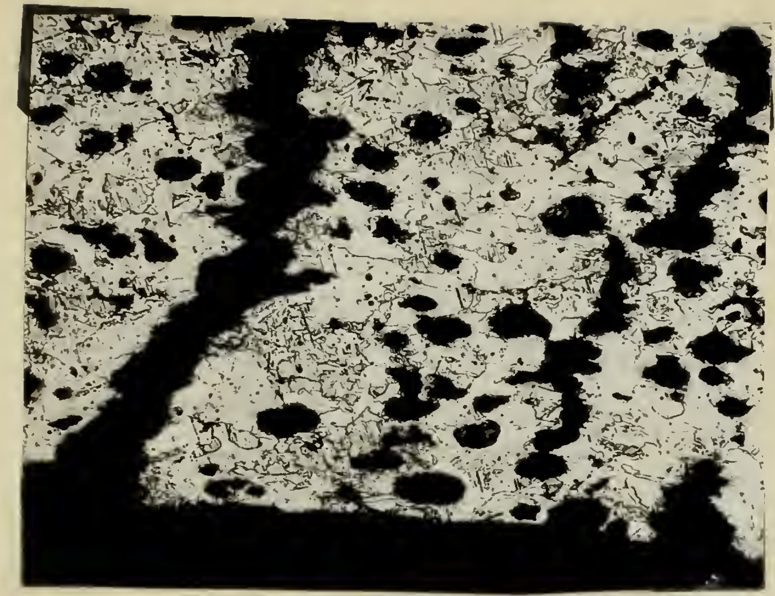


Figure 22.

Fractured specimen showing the fracture on the left and a secondary crack forming on the right.

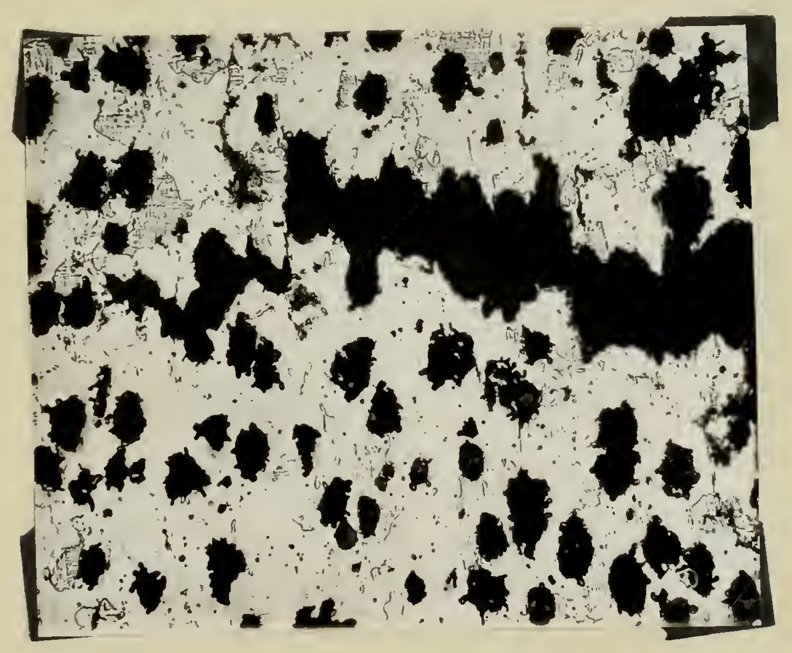


Figure 23.

Area adjacent to the crack in the specimen of Figure 20. The crack proceeds from spheroid to spheroid along grain boundaries.

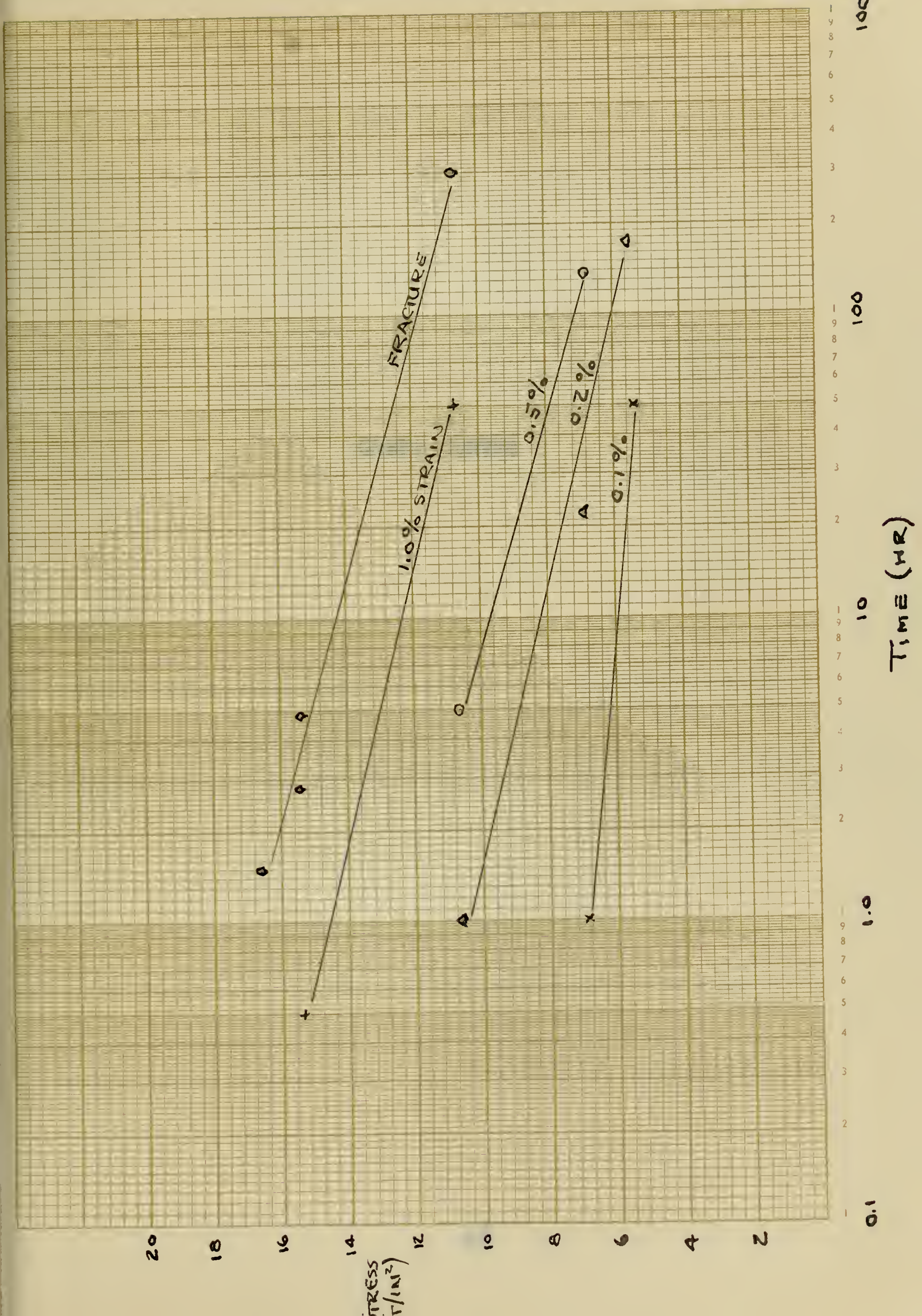
Appendix 1

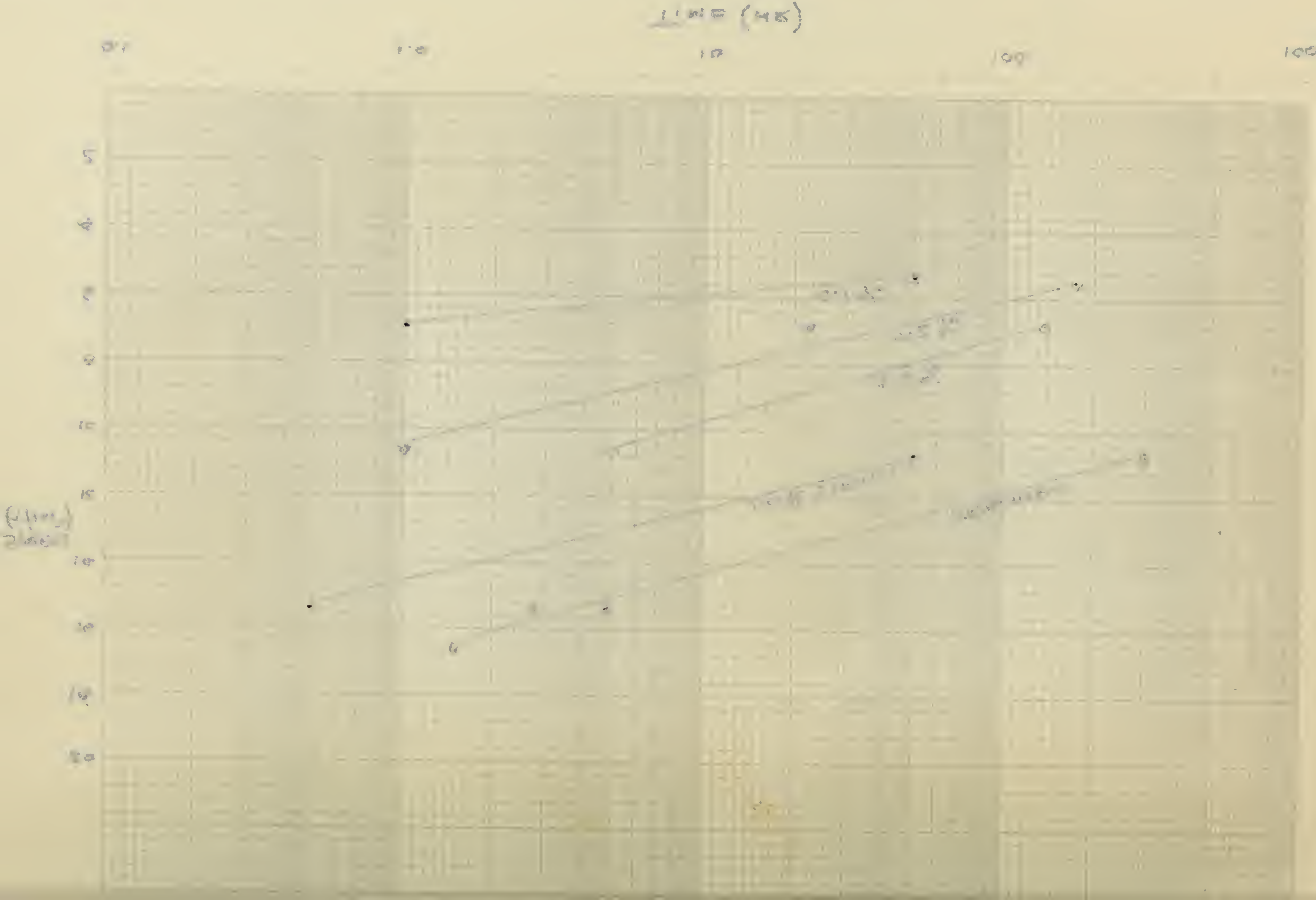
Creep Test Results.

STRESS - TIME DIAGRAM

STRESS - TIME DATA
SPHEROIDAL GRAPHITE CAST IRON
at 450°C

TEST	STRESS t.s.i.	TIME FOR CREEP STRAIN 0.1%	0.2%	0.5%	1.0%	Fracture
1	5.36	15.0	170	-	-	-
2	6.88	1.0	22	137	-	-
12	15.40	nil	nil	.033	0.15	4.9
17	16.47	nil	nil	nil	.008	1.5
18	15.47	nil	nil	nil	.03	2.8
19	10.67	nil	1.0	5.0	15	300.0


FRACTURE
1.0% STRAIN
0.5%
0.2%
0.1%
TIME (HR)
0.1
1.0
10
100
100
20
18
16
14
12
10
8
6
4
2
TRESS
T/IN²)

TIME (HR)
0.1
1.0
10
100
1000
2
4
6
8
10
12
14
16
18
20

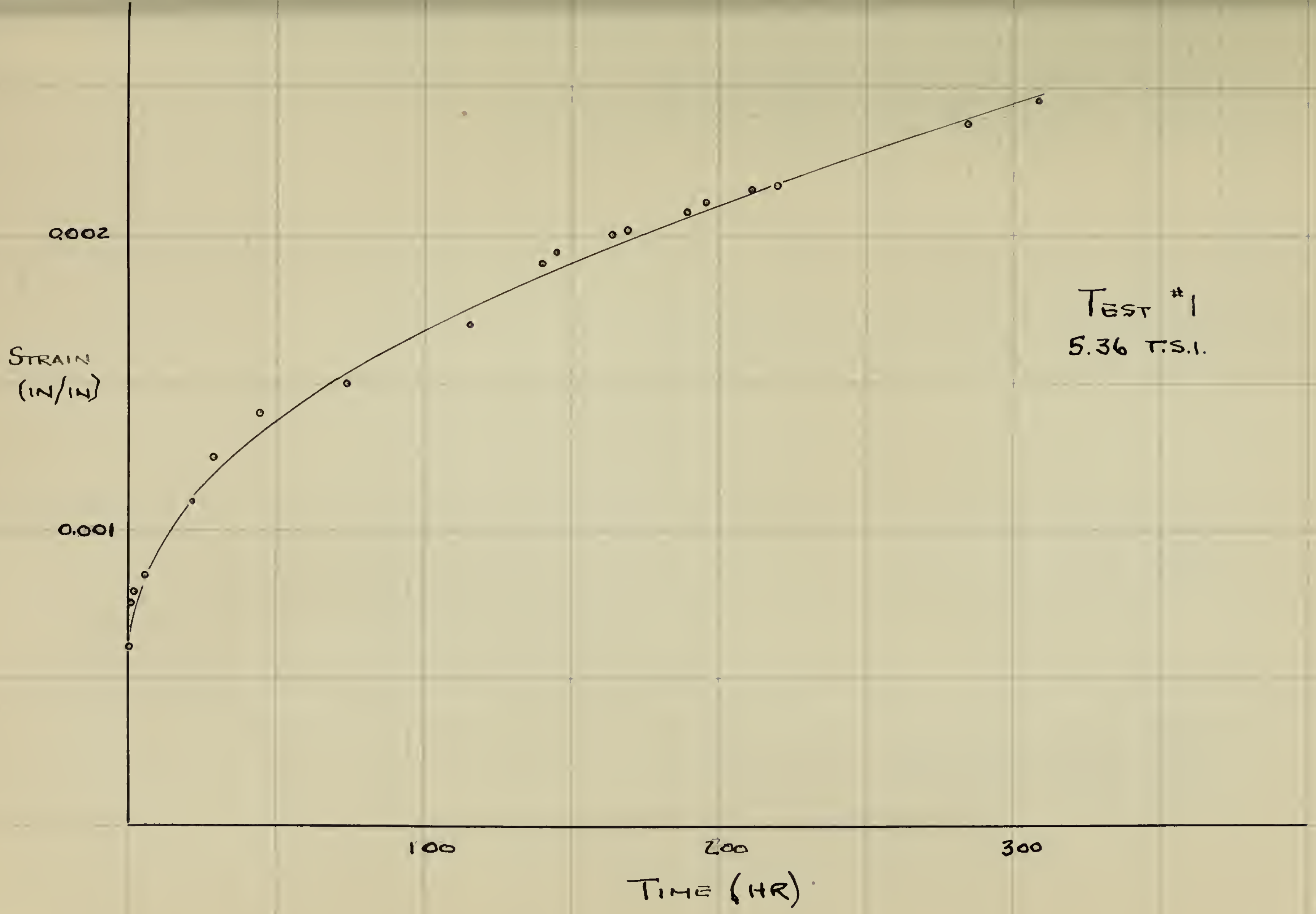
CREEP CURVES

TEST NO.1

Stress: 5.36 t.s.i.

Diameter: 0.356 in.

Time (hrs)	Strain (in/in)	Time (hrs)	Strain (in/in)
0	0.0006	169.4	0.00202
1.3	.0007	188.4	.00208
2.6	.00075	196.75	.0021
5.2	.0008	212.3	.00215
20.3	.0011	219.9	.00217
28.8	.00125	285.8	.00237
44.1	.0014	308.4	.00245
74.0	.0015		
116.3	.0017		
140.3	.0019		
145.3	.00195		
164.3	.0020		

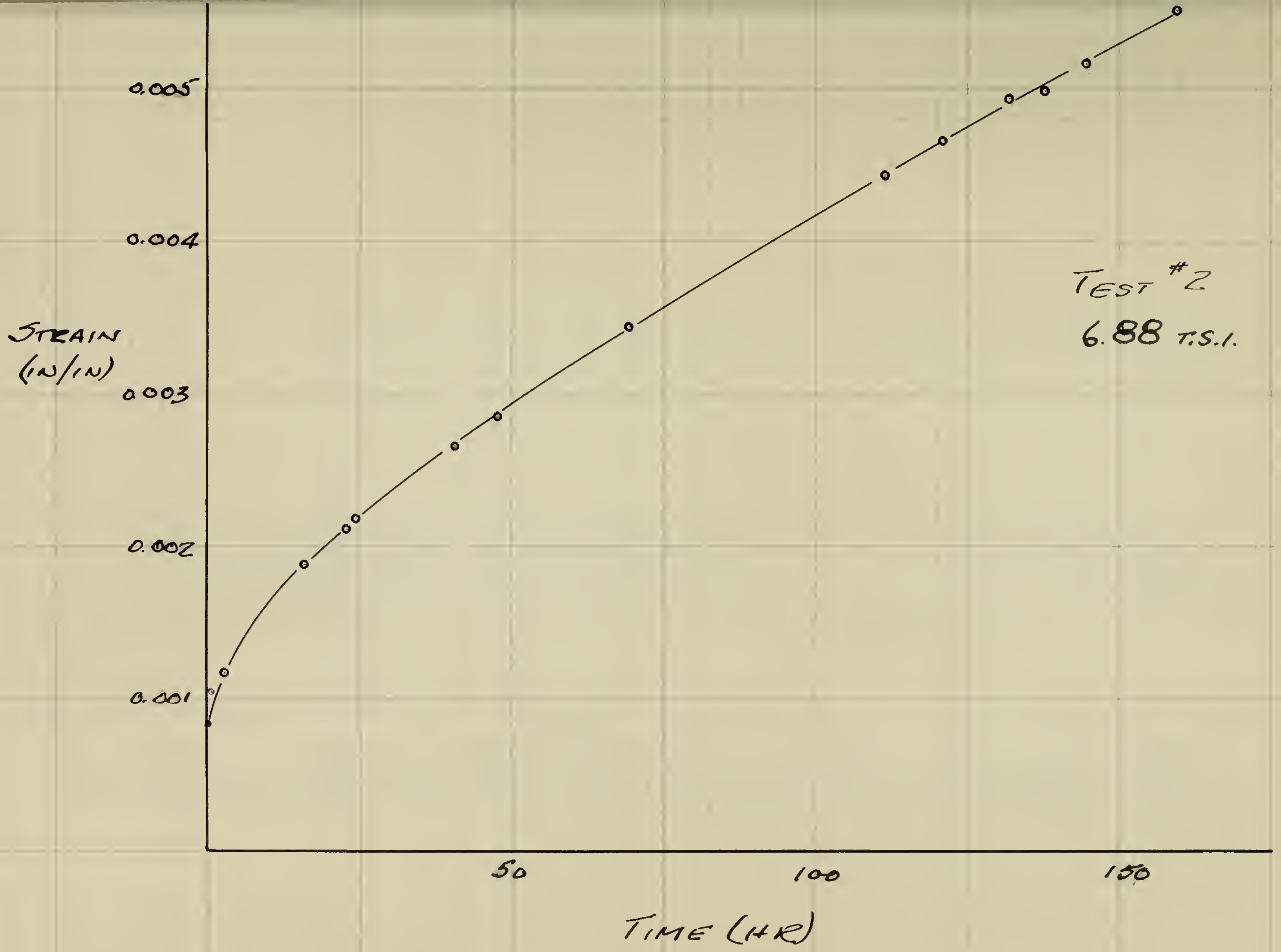

Test #1
5.36 T.S.I.
Strain (in/in)
0.002
0.001
Time (hr)
100
200
300

TEST NO.2

Stress: 6.88 t.s.i.

Diameter: 0.357 in.

Time (hrs)	Strain (in/in)	Time (hrs)	Strain (in/in)
0	.00084	121.3	.00465
1.0	.00104	132.3	.00496
2.8	.00118	137.8	.00499
16.7	.00188	144.7	.00519
23.3	.00211	159.5	.00552
24.8	.00219		
40.3	.00264		
47.8	.00286		
69.6	.00344		
112.2	.00442		


Test #2
6.88 T.S.I.
Strain (in/in)
0.005
0.004
0.003
0.002
0.001
50
100
150
Time (hr)

TEST NO. 12

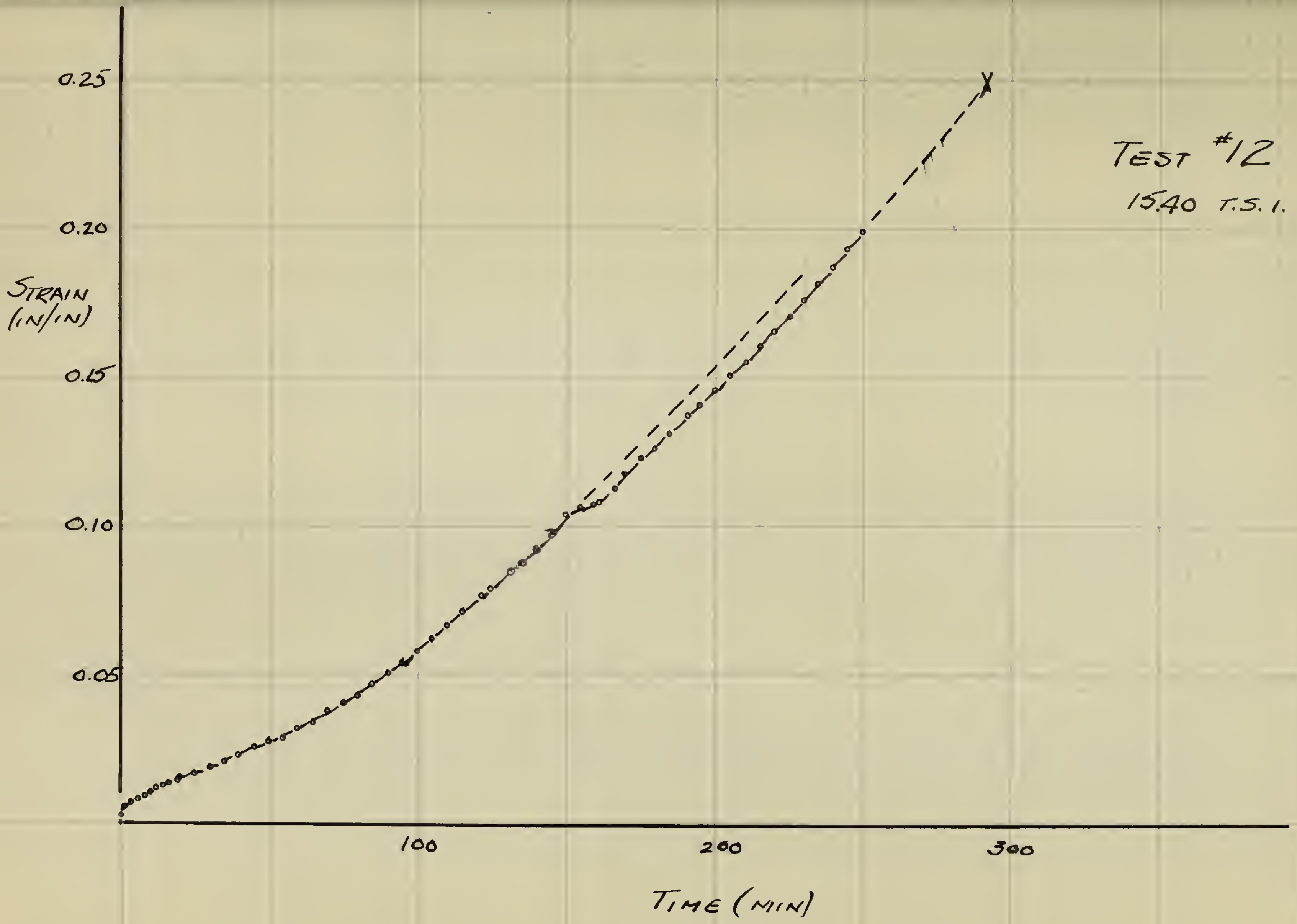
Stress: 15.40 t.s.i.

Diameter: 0.3568 in.

Time (min)	Strain (in/in)	Time (min)	Strain (in/in)
0	.0026	55	.0296
1	.0046	60	.0321
2	.0055	65	.0349
3	.0063	70	.0378
4	.0071	75	.0408
5	.0078	80	.0439
6	.0084	85	.0473
8	.0096	90	.0510
9	.0101	95	.0549
10	.0106	100	.0587
12	.0117	105	.0626
14	.0126	110	.0669
16	.0135	115	.0709
19	.0149	122	.0765
20	.0152	125	.0790
25	.0171	132	.0850
30	.0190	135	.0870
35	.0209	140	.0929
40	.0229	146	.0986
45	.0251	150	.1046
50	.0276	155	.1071

Test No. 12 (con't)

Time (min)	Strain (in/in)	Time (min)	Strain (in/in)
159	.1084	210	.1552
161	.1095	215	.1601
166	.1140	220	.1652
170	.1176	225	.1703
175	.1223	230	.1755
180	.1254	235	.1810
185	.1316	240	.1871
191	.1375	245	.1933
195	.1409	250	.1996
200	.1457	292	Fracture
205	.1504		


Test #12
15.40 T.S.I.
0.25
0.20
Strain (in/in)
0.15
0.10
0.05
100
200
300
Time (min)

TEST NO. 17

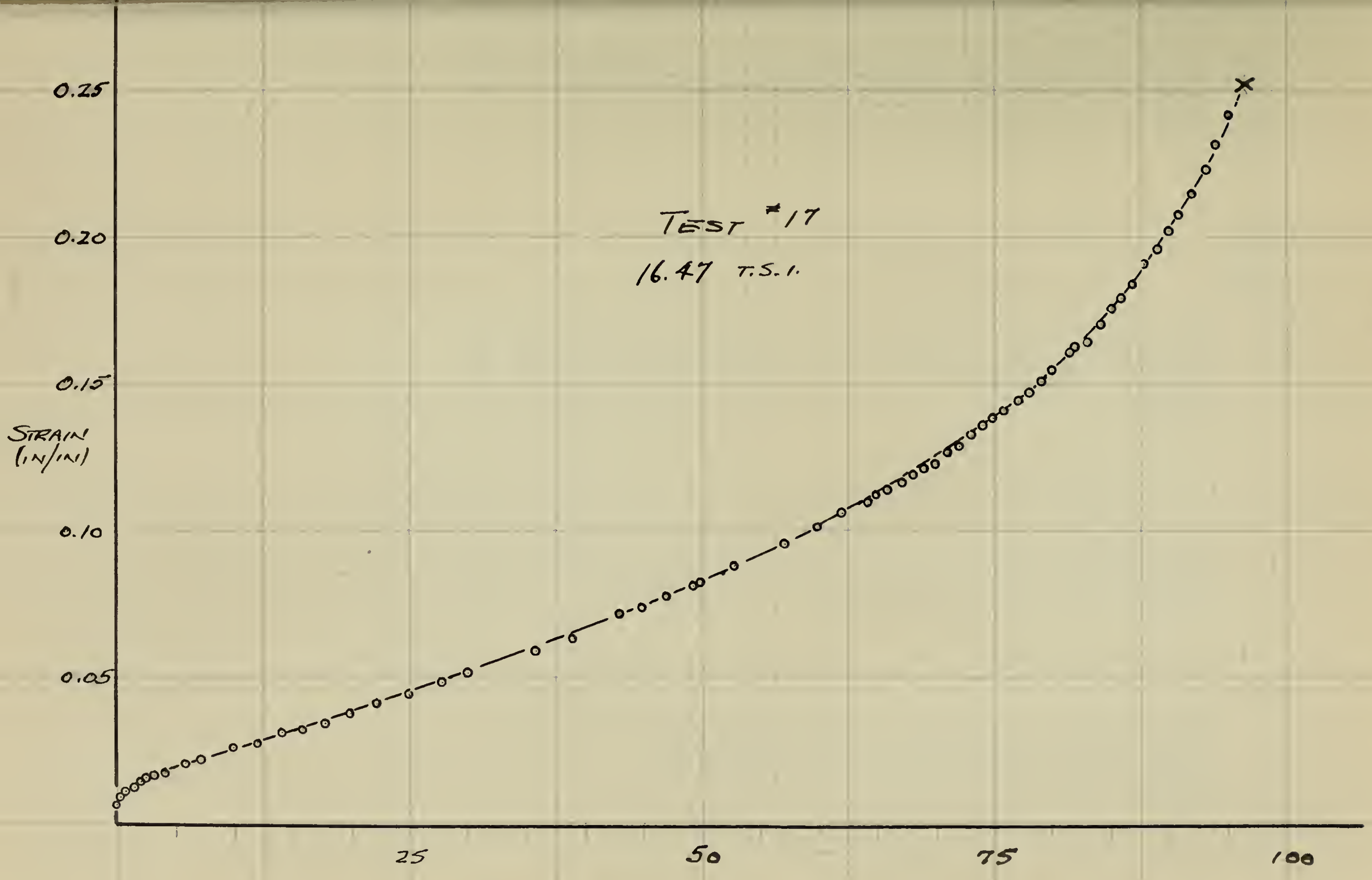
Stress: 16.47 t.s.i.

Diameter 0.3565 in.

Time (min)	Strain (in/in)	Time (min)	Strain (in/in)
0.0	.0064	33	.0554
0.5	.0095	36	.0599
1	.0112	39	.0643
1.5	.0124	43	.0706
2	.0137	45	.0738
2.5	.0147	47	.0771
3	.0157	49	.0805
4	.0174	50	.0822
6	.0203	53	.0878
7	.0217	57	.0951
10	.0256	60	.1013
12	.0279	62	.1057
14	.0302	64	.1076
16	.0322	65	.1124
18	.0345	66	.1148
20	.0374	66.5	.1156
22	.0401	67	.1169
25	.0442	68	.1194
28	.0483	69	.1219
30	.0511	70	.1245

Test No. 17 (con't)

Time (min)	Strain (in/in)	Time (min)	Strain (in/in)
71	.1271	84	.1706
72	.1298	85	.1752
73	.1326	86	.1799
74	.1353	87	.1848
75	.1382	88	.1901
76	.1412	89	.1953
77	.1444	90	.2013
78	.1477	91	.2078
79	.1512	92	.2148
80	.1547	93	.2227
81.5	.1604	94	.2314
82	.1624	95	.2414
83	.1640	96	Fracture



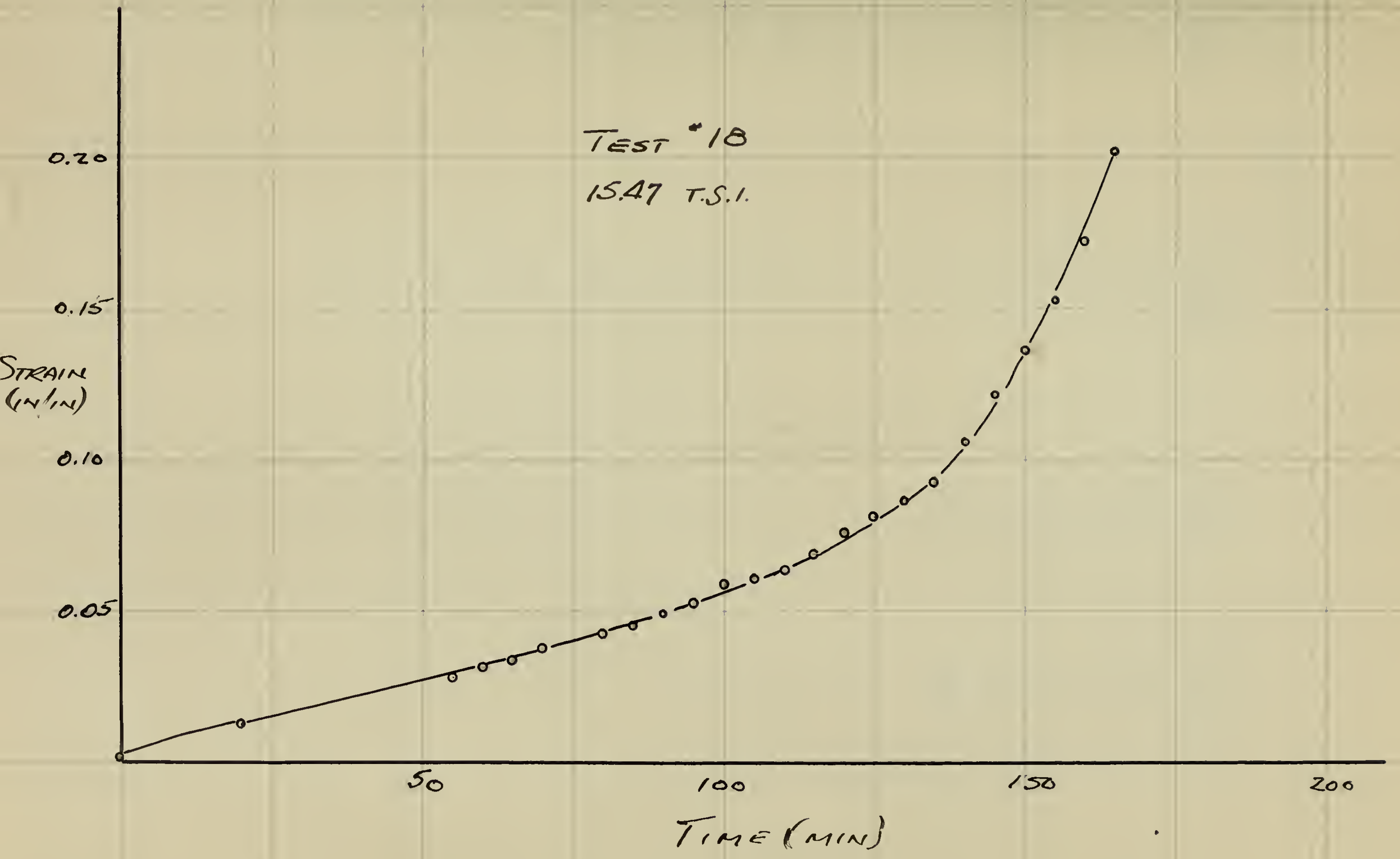
Test #17
16.47 T.S.I.

TEST NO. 18

Stress: 15.47 t.s.i.

Diameter: 0.3558

Time (min)	Strain (in/in)	Time (min)	Strain (in/in)
0	.0009	120	.0752
20	.0125	125	.0812
55	.0282	130	.0866
60	.0322	135	.0932
65	.0349	140	.1057
70	.0373	145	.1207
80	.0423	150	.1359
85	.0455	155	.1532
90	.0495	160	.1735
95	.0538	165	.2017
100	.0592		
105	.0602		
110	.0636		
115	.0692		

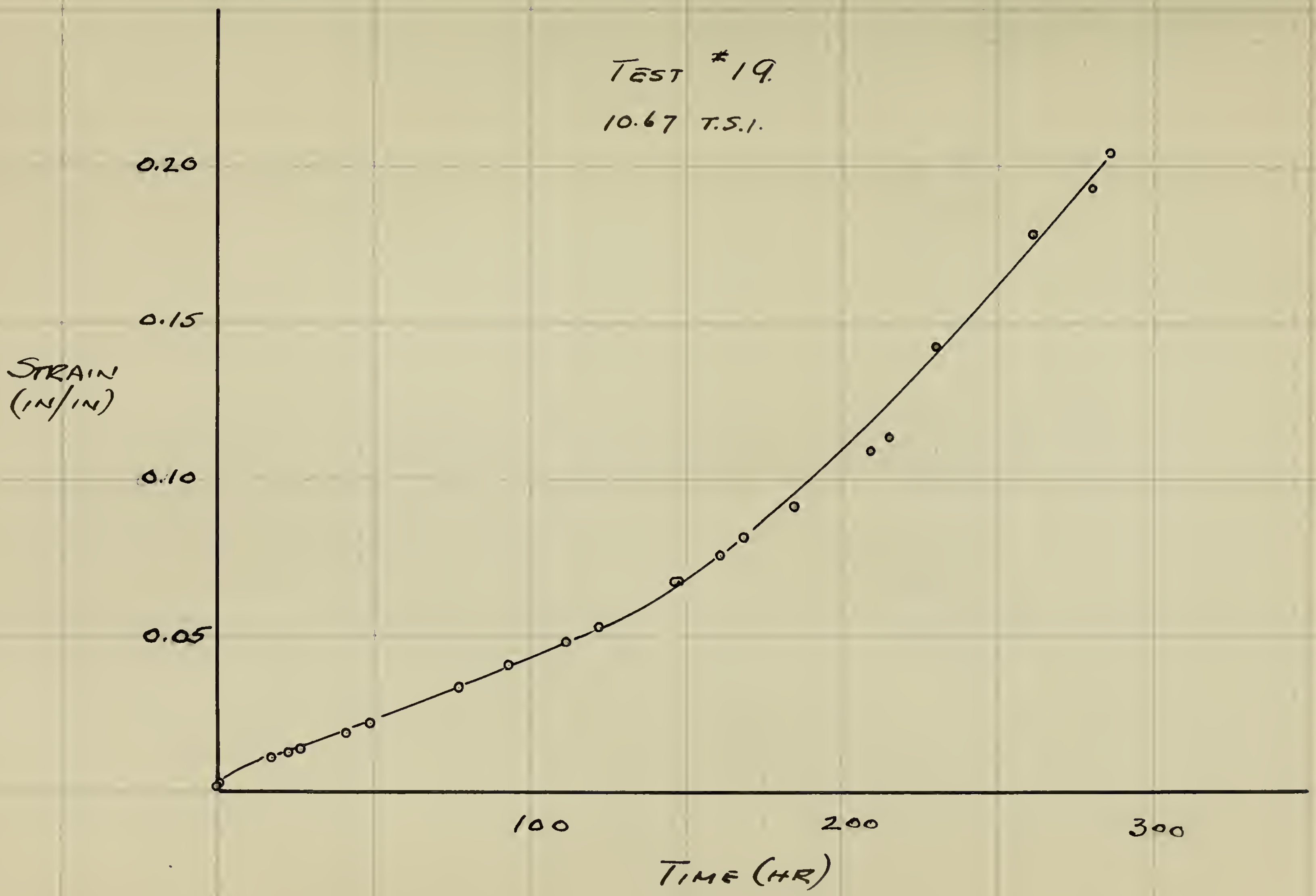

Test #18
15.47 T.S.I.
0.20
0.15
0.10
0.05
Strain (in/in)
50
100
150
200
Time (min)

TEST NO. 19

Stress: 10.67 t.s.i.

Diameter: .3562 in.

Time (hrs)	Strain (in/in)	Time (hrs)	Strain (in/in)
0.0	.0013	216.7	.1141
1.2	.0029	230.9	.1437
17.3	.0107	262.5	.1783
24.5	.0133	281.3	.1923
25.9	.0138	286.9	.2045
41.1	.0193		
49.0	.0222		
77.5	.0331		
94.7	.0402		
113.3	.0489		
122.3	.0537		
146.1	.0664		
148.2	.0675		
161.3	.0752		
169.6	.0803		
185.3	.0912		
209.6	.1089		


TEST *19.
10.67 T.S.I.
STRAIN (IN/IN)
0.20
0.15
0.10
0.05
100
200
300
TIME (HR)

Appendix 2

Summary of Published High Temperature Properties of Spheroidal Graphite Cast Iron.

Appendix 2.

Summary of Published High-Temperature Properties and Creep Data on S. G. Cast Iron

(a) Short-Time Tensile Tests

Condition	Temperature °C.	Elongation %	U.T.S. t.s.i.	Source of data
Pearlitic (as cast)	R.T.	3.0	33.5	1
	427	3.0	32.5	
	482	1.0	22.8	
	538	3.0	18	
	593	6.5	12.8	
	650	11.0	7.8	
	427	1.0	37.3	2
	538	3.0	27.2	
	650	16.0	11.5	
Pearlitic-ferritic (partially annealed)	R.T.	2.5	35.7	1
	427	4.5	32.8	
	482	3.0	21.5	
	538	3.5	18.3	
	593	6.0	12.2	
	650	11.0	6.7	
Ferritic (annealed)	427	4.0	19.8	2
	538	8.0	11.2	
	650	11.0	4.8	
Austenitic	427	23.0	23.3	2
	538	19.0	18.8	
	650	10.0	12.5	

(b) Stress-Rupture Tests

Condition	Temperature °C.	Elongation %	Time Hours	Ultimate Load t.s.i.	Source of data
Pearlitic (as cast)	427		100	24	2
	538		100	8.5	
	650		100	1.7	
	650	11	S.T.T*	7.8	1
	650	26	2.8	4.7	
	650	12	7.0	4.4	
	650	15.5	46	2.7	
	650	5.7	38	2.2	
	650	18	110	1.85	
	650	8.0	830	1.35	
Pearlitic-ferritic (partially annealed)	650	11	S.T.T	6.65	1
	650	29.5	5.2	3.8	
	650	13	13.7	2.7	
	650	17.5	22.6	2.0	
	650	19.0	284.4	1.35	
	650	15.0	404.8	1.2	
	650	15.0	1272.0	1.07	
Ferritic (annealed)	427		100	13.5	2
	538		100	4.5	
	650		100	1.5	
Austenitic	427		100	18	2
	538		100	11.5	
	650		100	4.9	

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* Short-Time Tensile.

(c) Creep Tests

Condition	Temperature °C.	Elongation %	Time Hours	Load t.s.i.	Source of data
Pearlitic (as cast)	450	0.1	1,000	3.8	3
	427	1.0	10,000	9.8	2
	538	1.0	10,000	1.3	
	650	1.0	10,000	0.18	
Ferritic (annealed)	450	0.1	1,000	3.2	3
	427	1.0	10,000	7.1	2
	538	1.0	10,000	1.8	
	650	1.0	10,000	0.27	
Austenitic	427	1.0	10,000	8.9	2
	538	1.0	10,000	5.8	
	650	1.0	10,000	2.5	

Sources of the above information :-

1. Saunders, M.S. and Sinnott, M.J.
"Some Properties of a Nodular Iron at Elevated Temperatures", Trans. Amer. Soc. for Metals 1953, vol. 45, pp. 362-376.

2. American Brake Shoe Co. "Ductalloy".
Publication issued in 1953.

3. Stauffer, W.
"Some Applications of Spheroidal-Graphite Cast Iron".
5th International Mechanical Engineering Congress, Turin, 1953.

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